Untitled3

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R Markdown

This is an R Markdown document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see http://rmarkdown.rstudio.com.

When you click the **Knit** button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document. You can embed an R code chunk like this:

```
Sys.time()
```

```
## [1] "2022-03-10 11:30:37 PST"
```

```
library(tinytex)
library(tidyverse)
library(cowplot)
library(Cairo)
library(modelr)
library(gridExtra)
library(mixtools)
library(nlme)
library(car)
library(emmeans)
library(MuMIn)
library(ggpmisc)
library(gtable)
library(grid)
library(RColorBrewer)
library(segmented)
library(data.table)
library(scales)
library(sm)
library(rcompanion)
library(nlstools)
```

DATA

GreenSeeker NDVI Data

```
gs_ndvi_data <- read_csv(file = "DATA/PI_greenseeker_data.csv")
```

```
## Rows: 328 Columns: 17
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr  (5): site_year, NDVI_1, NDVI_2, NDVI_3, NDVI_4
## dbl (12): year, exp_plot_number, block, plot, N_level, N_level_kgha, biomass...
```

```
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
str(gs_ndvi_data , give.attr = FALSE)
```

```
## spec_tbl_df [328 x 17] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ site_year          : chr [1:328] "Arbuckle-15" "Arbuckle-15" "Arbuckle-15" "Arbuckle-15" ...
##  $ year               : num [1:328] 2015 2015 2015 2015 2015 ...
##  $ exp_plot_number    : num [1:328] 101 102 103 104 105 201 202 203 204 205 ...
##  $ block              : num [1:328] 1 1 1 1 1 2 2 2 2 2 ...
##  $ plot               : num [1:328] 1 2 3 4 5 1 2 3 4 5 ...
##  $ N_level            : num [1:328] 125 225 0 75 175 0 175 125 225 75 ...
##  $ N_level_kgha       : num [1:328] 125 225 0 75 175 0 175 125 225 75 ...
##  $ biomass_plus_bag_g: num [1:328] 414 472 281 386 455 304 402 322 418 336 ...
##  $ paper_bag_g        : num [1:328] 45 45 45 45 45 45 45 45 45 45 ...
##  $ ring_size          : num [1:328] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ num_of_paper_bags : num [1:328] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg   : num [1:328] 4.84 5.12 4.78 5.15 4.93 ...
##  $ sample_N_ug        : num [1:328] 117.1 153.4 64.9 92.9 116 ...
##  $ NDVI_1             : chr [1:328] "0.77" "0.82" "0.56" "0.72" ...
##  $ NDVI_2             : chr [1:328] "n/a" "n/a" "n/a" "n/a" ...
##  $ NDVI_3             : chr [1:328] "n/a" "n/a" "n/a" "n/a" ...
##  $ NDVI_4             : chr [1:328] "n/a" "n/a" "n/a" "n/a" ...
```

```r
gs_ndvi_data <- gs_ndvi_data %>%
  filter(!year %in% c("2015" , "2016") & N_level_kgha != 275) #remove the years we don't need for this

str(gs_ndvi_data , give.attr = FALSE)
```

```
## spec_tbl_df [240 x 17] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ site_year          : chr [1:240] "Nicolaus-17" "Nicolaus-17" "Nicolaus-17" "Nicolaus-17" ...
##  $ year               : num [1:240] 2017 2017 2017 2017 2017 ...
##  $ exp_plot_number    : num [1:240] 101 102 103 104 106 107 202 203 204 205 ...
##  $ block              : num [1:240] 1 1 1 1 1 1 2 2 2 2 ...
##  $ plot               : num [1:240] 1 2 3 4 6 7 2 3 4 5 ...
##  $ N_level            : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha       : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ biomass_plus_bag_g: num [1:240] 361 264 318 360 285 ...
##  $ paper_bag_g        : num [1:240] 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 ...
##  $ ring_size          : num [1:240] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ num_of_paper_bags : num [1:240] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg   : num [1:240] 3.17 3.42 3.09 3.07 3.2 ...
##  $ sample_N_ug        : num [1:240] 79.4 61.1 80.7 95.9 63.6 ...
##  $ NDVI_1             : chr [1:240] "0.77" "0.50" "0.67" "0.79" ...
##  $ NDVI_2             : chr [1:240] "0.77" "0.52" "0.67" "0.78" ...
##  $ NDVI_3             : chr [1:240] "0.79" "0.46" "0.71" "0.79" ...
##  $ NDVI_4             : chr [1:240] "n/a" "n/a" "n/a" "n/a" ...
```

```r
gs_ndvi_data <- gs_ndvi_data[c(1:240), c(1:17)] #removes the empty rows and columns from the data frame

gs_ndvi_data$block <- factor(gs_ndvi_data$block)
gs_ndvi_data$year <- factor(gs_ndvi_data$year)
gs_ndvi_data$plot <- factor(gs_ndvi_data$plot)
gs_ndvi_data$N_level_kgha_f <- factor(gs_ndvi_data$N_level_kgha)
gs_ndvi_data$exp_plot_number <- factor(gs_ndvi_data$exp_plot_number)
```

```r
gs_ndvi_data$site_year <- factor(gs_ndvi_data$site_year , levels = c( "Nicolaus-17" , "Williams-17" , "
gs_ndvi_data$NDVI_1 <- as.numeric(as.character(gs_ndvi_data$NDVI_1))
```

```
## Warning: NAs introduced by coercion
```

```r
gs_ndvi_data$NDVI_2 <- as.numeric(as.character(gs_ndvi_data$NDVI_2))
```

```
## Warning: NAs introduced by coercion
```

```r
gs_ndvi_data$NDVI_3 <- as.numeric(as.character(gs_ndvi_data$NDVI_3))
gs_ndvi_data$NDVI_4 <- as.numeric(as.character(gs_ndvi_data$NDVI_4)) #gets the data right
```

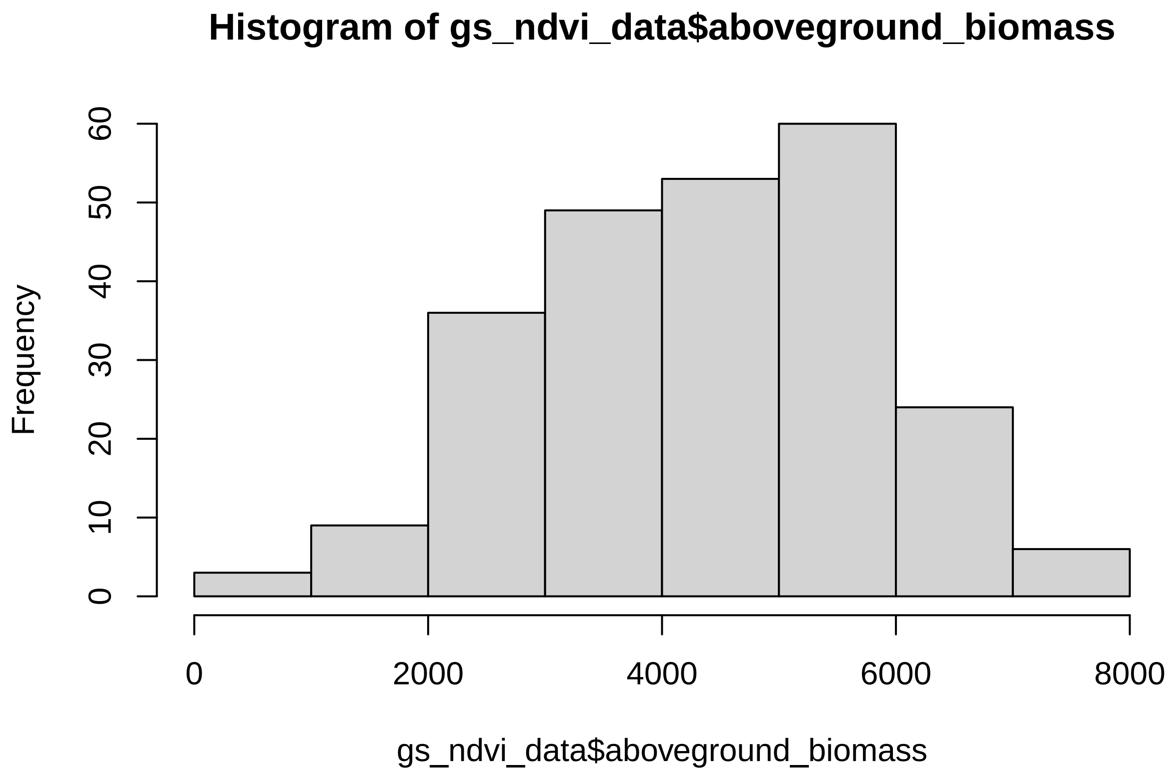
```
## Warning: NAs introduced by coercion
```

```r
str(gs_ndvi_data , give.attr = FALSE)
```

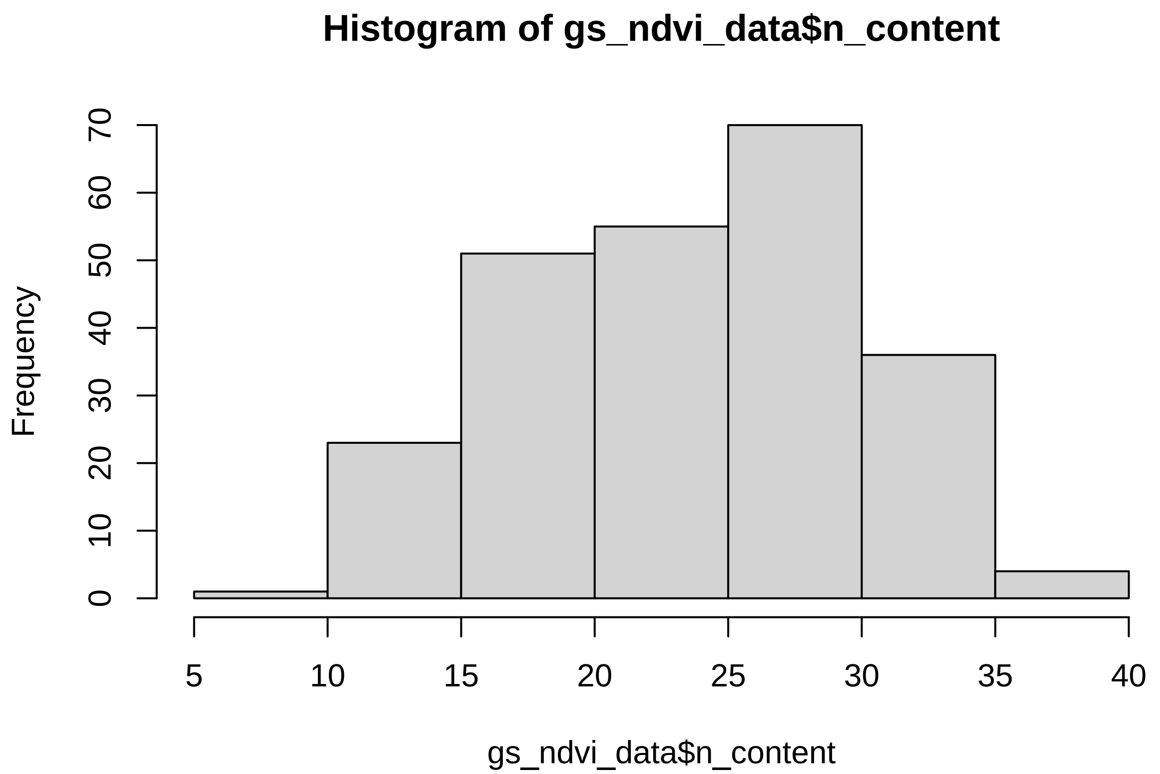
```
## tibble [240 x 18] (S3: tbl_df/tbl/data.frame)
##  $ site_year          : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year               : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number    : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ block              : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ plot               : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ N_level            : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha       : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ biomass_plus_bag_g: num [1:240] 361 264 318 360 285 ...
##  $ paper_bag_g        : num [1:240] 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 ...
##  $ ring_size          : num [1:240] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ num_of_paper_bags : num [1:240] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg  : num [1:240] 3.17 3.42 3.09 3.07 3.2 ...
##  $ sample_N_ug       : num [1:240] 79.4 61.1 80.7 95.9 63.6 ...
##  $ NDVI_1            : num [1:240] 0.77 0.5 0.67 0.79 0.68 0.63 0.66 0.68 0.54 0.77 ...
##  $ NDVI_2            : num [1:240] 0.77 0.52 0.67 0.78 0.69 0.56 0.65 0.68 0.5 0.75 ...
##  $ NDVI_3            : num [1:240] 0.79 0.46 0.71 0.79 0.68 0.53 0.63 0.64 0.5 0.77 ...
##  $ NDVI_4            : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ N_level_kgha_f    : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
```

```r
gs_ndvi_data <-  gs_ndvi_data %>%
  mutate( biomass_dry_wt = biomass_plus_bag_g - (paper_bag_g * num_of_paper_bags) ,
          aboveground_biomass = (biomass_dry_wt / ring_size) * 10 ,
          n_content = sample_N_ug / sample_weight_mg ,
          PI_N_Uptake = (aboveground_biomass * n_content) / 1000 #n uptake in kg per ha
          )#processes the data


gs_ndvi_data <- gs_ndvi_data %>%
  rowwise() %>%
  mutate(NDVI = mean(c( NDVI_1 , NDVI_2 , NDVI_3 , NDVI_4) , na.rm = T)) #takes average of four NDVI re

gs_ndvi_data <- dplyr::select(gs_ndvi_data ,
                        site_year,
                        year,
                        exp_plot_number,
                        block,
                        plot,
                        N_level_kgha,
                        aboveground_biomass,
```

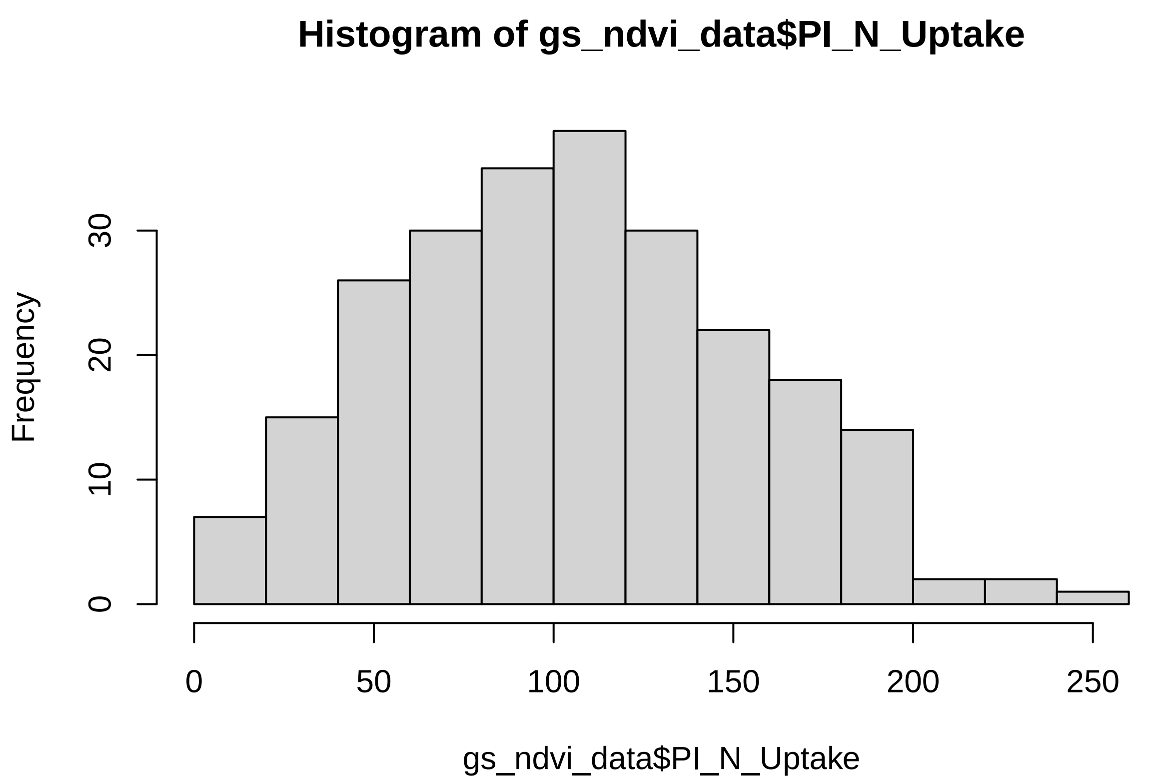
```
                      n_content,
                      PI_N_Uptake,
                      NDVI) #selects the relevant columns

gs_ndvi_data$site_year <- factor(gs_ndvi_data$site_year , levels = c( "Nicolaus-17" , "Williams-17" , "

hist(gs_ndvi_data$aboveground_biomass)
```




```
hist(gs_ndvi_data$n_content)
```




```
hist(gs_ndvi_data$PI_N_Uptake)
```



Yield Data

```
yield_data <- read_csv(file = "DATA/yield_data.csv")
```

```
## Rows: 672 Columns: 34
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr  (2): site_year, Received_TopDress
## dbl (32): year, Block, MainPlot, SubPlot, exp_plot_number, N_level, TopDress...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
str(yield_data , give.attr = FALSE)
```

```
## spec_tbl_df [672 x 34] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ site_year             : chr [1:672] "Davis-16" "Davis-16" "Davis-16" "Davis-16" ...
##  $ year                  : num [1:672] 2016 2016 2016 2016 2016 ...
##  $ Block                 : num [1:672] 1 1 1 1 1 2 2 2 2 2 ...
##  $ MainPlot              : num [1:672] 1 2 3 4 5 1 2 3 4 5 ...
##  $ SubPlot               : num [1:672] 3 1 3 2 1 2 3 2 3 2 ...
##  $ exp_plot_number       : num [1:672] 101 102 103 104 105 201 202 203 204 205 ...
##  $ N_level               : num [1:672] 75 225 0 125 175 75 0 225 175 125 ...
##  $ TopDress              : num [1:672] 0 0 0 0 0 0 0 0 0 0 ...
##  $ SeasonalNRate         : num [1:672] 75 225 0 125 175 75 0 225 175 125 ...
##  $ N_level_kgha          : num [1:672] 75 225 0 125 175 75 0 225 175 125 ...
##  $ TopDress_kgha         : num [1:672] 0 0 0 0 0 0 0 0 0 0 ...
##  $ SeasonalNRate_kgha    : num [1:672] 75 225 0 125 175 75 0 225 175 125 ...
##  $ Received_TopDress     : chr [1:672] "NO" "NO" "NO" "NO" ...
##  $ tare                  : num [1:672] 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 ...
##  $ FW1PlusTare           : num [1:672] 5662 5298 5256 4846 5220 ...
##  $ FW2PlusTare           : num [1:672] 4610 5438 1220 4278 5156 ...
##  $ SSFWPlusTare          : num [1:672] 3070 3262 2266 2482 2650 ...
##  $ SSODW                 : num [1:672] 692 705 519 541 538 ...
##  $ HarvestBagPlusTie     : num [1:672] 121 122 122 121 122 ...
##  $ Grain1PlusPaperBag1   : num [1:672] 292 271 188 215 208 ...
##  $ PaperBag1             : num [1:672] 7.92 7.92 7.92 7.92 7.92 7.92 7.92 7.92 7.92 7.92 ...
##  $ Grain2PlusPaperBag2   : num [1:672] 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 ...
##  $ PaperBag2             : num [1:672] 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 ...
##  $ StrawSampleSize       : num [1:672] 8.27 7.74 7.9 8.38 7.52 ...
##  $ StrawN                : num [1:672] 55.1 55.2 49.4 47.1 45.3 ...
##  $ GrainSampleSize       : num [1:672] 4.95 4.97 5.04 5.02 4.57 ...
##  $ GrainN                : num [1:672] 54.5 58.6 47.4 52.5 46.1 ...
##  $ DaysPI2Harvest        : num [1:672] 102 102 102 102 102 102 102 102 102 102 ...
##  $ SeedTray1.1           : num [1:672] 243 243 243 243 243 243 243 243 243 243 ...
##  $ SeedTray1.2           : num [1:672] 0.62 0.62 0.62 0.64 0.64 0.62 0.62 0.62 0.62 0.62 ...
##  $ Grain3PlusSeedTray1   : num [1:672] 435 514 426 455 447 ...
##  $ MoistureContentGrain3: num [1:672] 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11.2 ...
##  $ SeedTray2             : num [1:672] 244 244 244 244 244 ...
##  $ Grain4PlusSeedTray2   : num [1:672] 254 254 254 254 254 ...
```

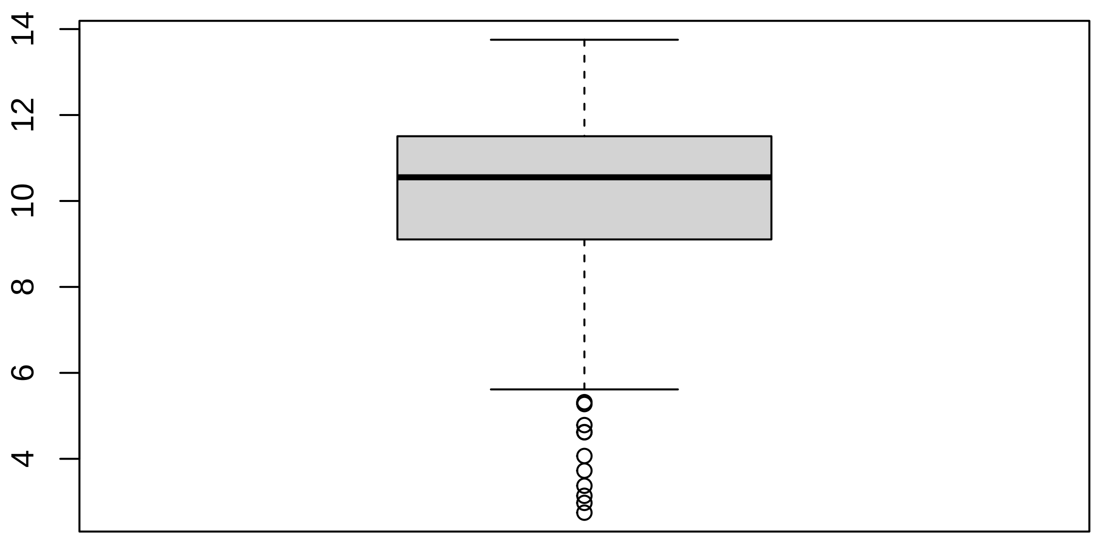
```
yield_data <- yield_data %>%
  filter(!year %in% c( "2016") & TopDress_kgha == 0 & N_level_kgha != 275) #removing the years and  N r

yield_data <- yield_data %>%
```

```r
  mutate(
    site_year = factor(site_year),
    year = factor(year),
    Block = factor(Block),
    MainPlot = factor(MainPlot),
    exp_plot_number = factor(exp_plot_number),
    N_level = factor(N_level),
    SubPlot = factor(SubPlot),
    TopDress = factor(TopDress),
    SeasonalNRate_f = factor(SeasonalNRate),
    N_level_kgha_f = factor(N_level_kgha),
    TopDress_kgha_f = factor(TopDress_kgha),
    SeasonalNRate_kgha_f = factor(SeasonalNRate_kgha)
    ) #changes these columns to factor

str(yield_data , give.attr = FALSE)
```

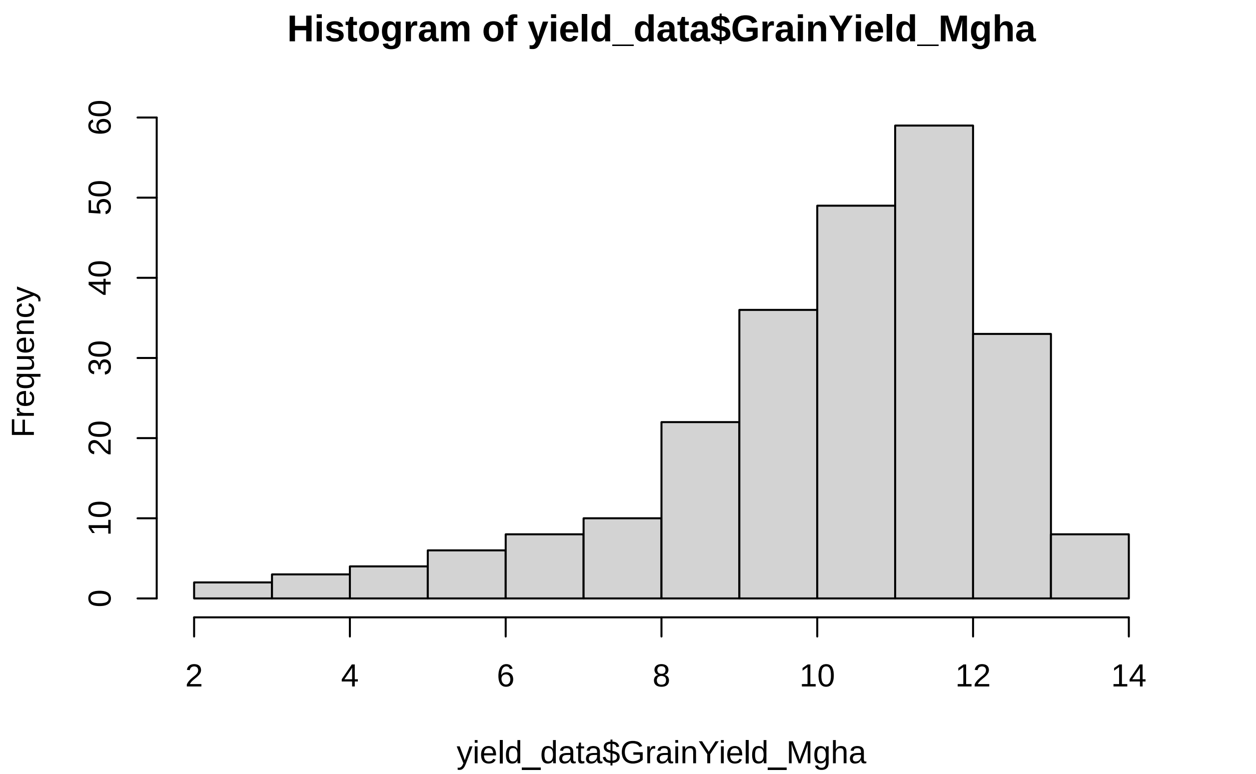
```
## tibble [240 x 38] (S3: tbl_df/tbl/data.frame)
##  $ site_year            : Factor w/ 10 levels "Arbuckle-18",..: 7 7 7 7 7 7 7 7 7 7 ...
##  $ year                 : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ Block                : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot             : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ SubPlot              : Factor w/ 3 levels "1","2","3": 2 3 1 1 1 2 1 1 2 3 ...
##  $ exp_plot_number      : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ N_level              : Factor w/ 11 levels "0","45","75",..: 11 1 6 8 2 3 3 6 1 8 ...
##  $ TopDress             : Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ SeasonalNRate        : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha         : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ TopDress_kgha        : num [1:240] 0 0 0 0 0 0 0 0 0 0 ...
##  $ SeasonalNRate_kgha   : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ Received_TopDress    : chr [1:240] "NO" "NO" "NO" "NO" ...
##  $ tare                 : num [1:240] 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 ...
##  $ FW1PlusTare          : num [1:240] 4360 4818 5376 5598 4852 ...
##  $ FW2PlusTare          : num [1:240] 3254 1220 1220 1220 1220 ...
##  $ SSFWPlusTare         : num [1:240] 2324 1814 1994 2126 2106 ...
##  $ SSODW                : num [1:240] 632 479 570 562 583 ...
##  $ HarvestBagPlusTie    : num [1:240] 162 176 169 121 120 ...
##  $ Grain1PlusPaperBag1  : num [1:240] 230 173 211 233 265 ...
##  $ PaperBag1            : num [1:240] 7.96 7.96 7.96 7.96 7.96 7.96 7.96 7.96 7.96 7.96 ...
##  $ Grain2PlusPaperBag2  : num [1:240] 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 ...
##  $ PaperBag2            : num [1:240] 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 7.01 ...
##  $ StrawSampleSize      : num [1:240] 8.25 7.96 7.76 7.89 8.45 ...
##  $ StrawN               : num [1:240] 63.5 36 46.1 55.9 39.7 ...
##  $ GrainSampleSize      : num [1:240] 4.97 5.52 5.23 5.72 5.82 ...
##  $ GrainN               : num [1:240] 60.5 50 56 66.7 51.1 ...
##  $ DaysPI2Harvest       : num [1:240] 76 76 76 76 76 76 76 76 76 76 ...
##  $ SeedTray1.1          : num [1:240] 243 243 243 243 243 243 243 243 243 243 ...
##  $ SeedTray1.2          : num [1:240] 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 ...
##  $ Grain3PlusSeedTray1  : num [1:240] 470 410 449 471 504 ...
##  $ MoistureContentGrain3: num [1:240] 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11.2 ...
##  $ SeedTray2            : num [1:240] 244 244 244 244 244 ...
##  $ Grain4PlusSeedTray2  : num [1:240] 254 254 254 254 254 ...
##  $ SeasonalNRate_f      : Factor w/ 11 levels "0","45","75",..: 11 1 6 8 2 3 3 6 1 8 ...
##  $ N_level_kgha_f       : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
```

```
##  $ TopDress_kgha_f      : Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ SeasonalNRate_kgha_f : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
```

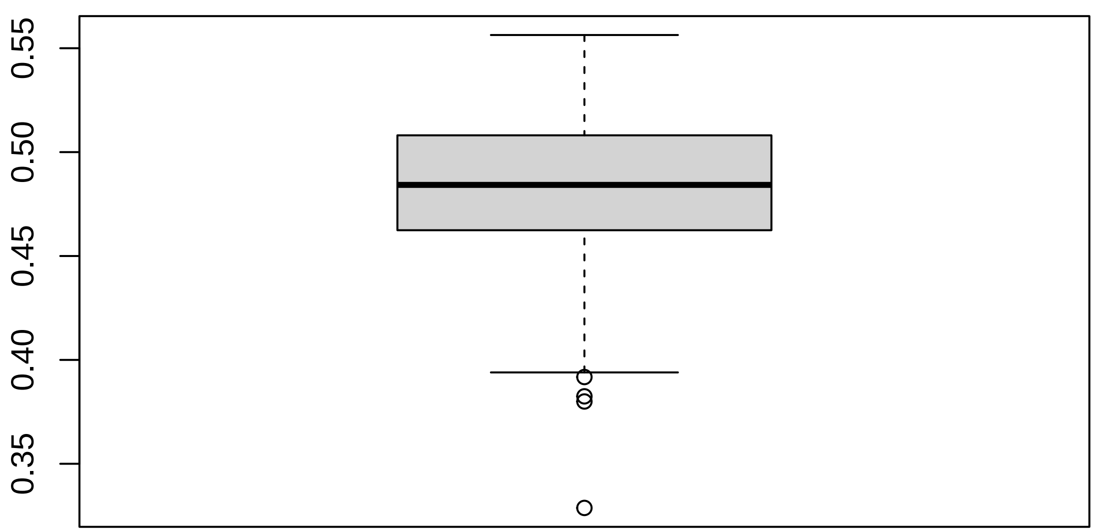
```
yield_data <- yield_data %>%
  mutate(
    FW1net = FW1PlusTare - tare,
    FW2net = FW2PlusTare - tare,
    TotalFW = FW1net + FW2net,
    SSFWnet = SSFWPlusTare - tare,
    Ratio = SSFWnet / TotalFW,
    SSODWnet = SSODW - HarvestBagPlusTie,
    SeedTray1 = SeedTray1.1 + SeedTray1.2, #adds the decimal to the 243g to get the tare weight for the
    Grain3net = Grain3PlusSeedTray1 - SeedTray1, #subtract tare of seed tray from grain3. Grain3 is the
    Grain4net = Grain4PlusSeedTray2 - SeedTray2, #grain4 is the amount of grain removed for ballmilling
    Grain2net = Grain2PlusPaperBag2 - PaperBag2, #yield component grain sample
    Grain2net = Grain2net * Ratio, #this essentially subsamples the yield component grain sample
    GrainNet = Grain3net + Grain4net + Grain2net, #add the grain removed for ball milling and yield com
    GrainRing = GrainNet / Ratio, #the amount of grain in the entire m^2 ring in grams
    GrainYield = GrainRing * 10, #g/m^2 to kg/ha
    GrainYield_kgha = GrainYield * ((100-MoistureContentGrain3)/86),#corrects for 14% moisture based on
    GrainYield_Mgha = GrainYield_kgha / 1000 , #converts kg/ha to Mg/ha
    Grain5 = GrainRing * ((100-MoistureContentGrain3)/98.1), #grain in the ring if the subsample was at
    Grain6 = GrainNet * ((100-MoistureContentGrain3)/98.1), #grain in the subsample if it was at 1.9% m
    StrawSS = SSODWnet - Grain6 , #just straw in subsample in grams
    StrawRing = StrawSS / Ratio, #straw in ring in grams i.e g/m2
    StrawNcon = StrawN / StrawSampleSize,
    StrawNup = (StrawRing * StrawNcon) / 100, #straw Nup divide by 100 to convert mg/m2 to kg/ha - this
    GrainNcon = (GrainN / GrainSampleSize), #grain in ring in kg/ha
    GrainNup = (Grain5 * GrainNcon) / 100, #grain Nup divide by 100 to convert mg N/m2 to kg N/ha
    TotalSeasonalNup = StrawNup + GrainNup, #in kg/ha
    HarvestIndex = Grain5 / (Grain5 + StrawRing),
    Moisture = SSFWnet / SSODWnet
    )

boxplot(yield_data$GrainYield_Mgha)
```



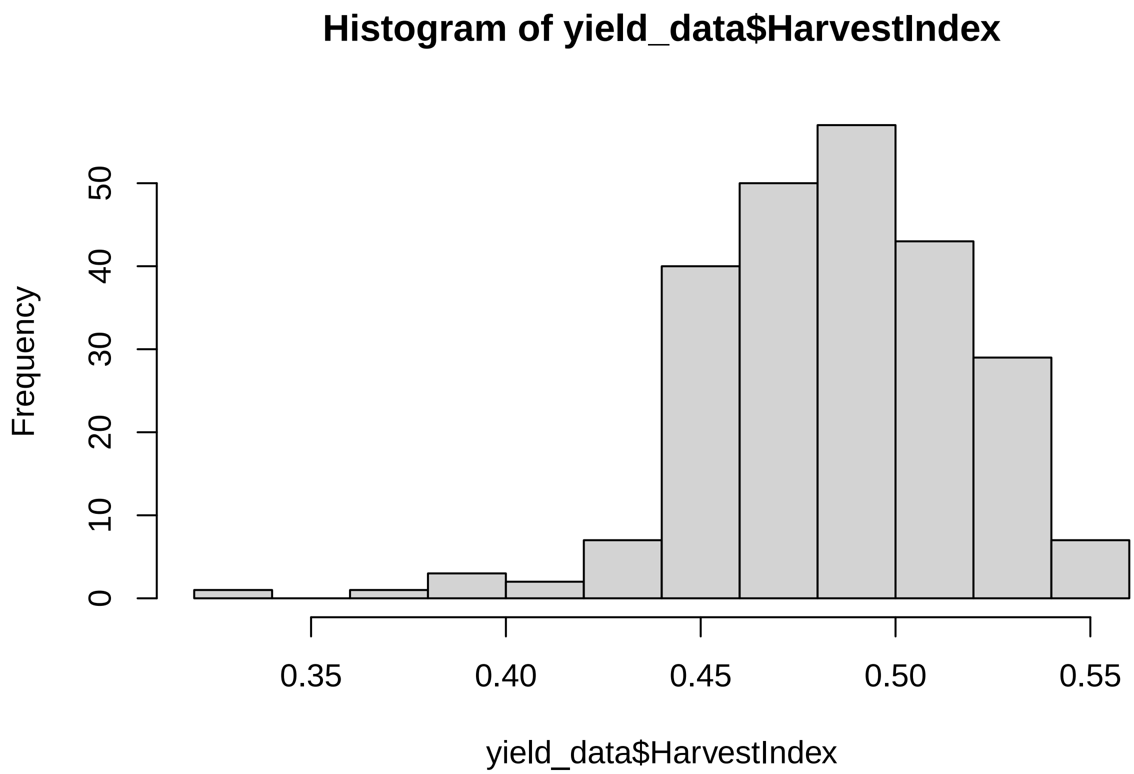
```
hist(yield_data$GrainYield_Mgha)
```



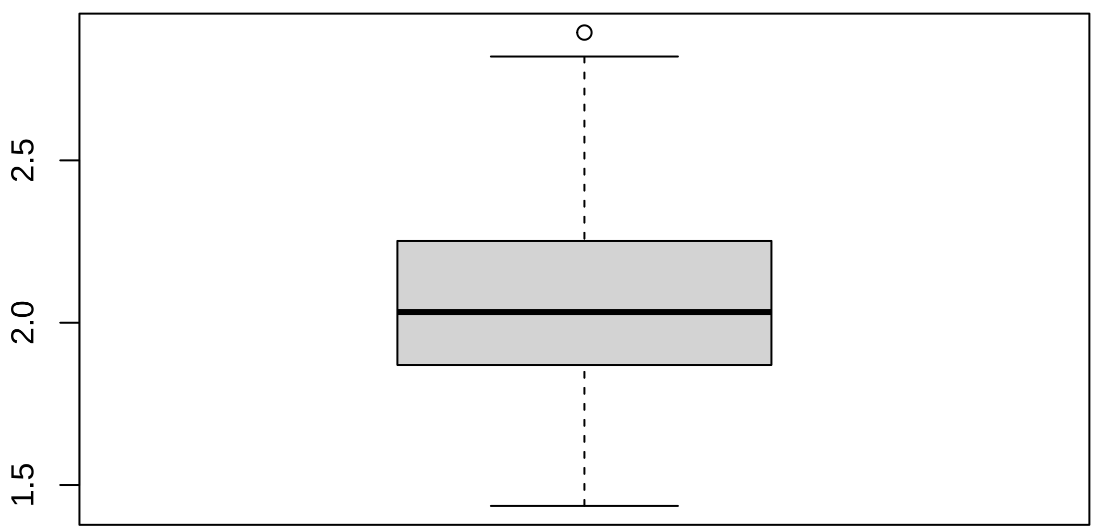

```
boxplot(yield_data$HarvestIndex)
```



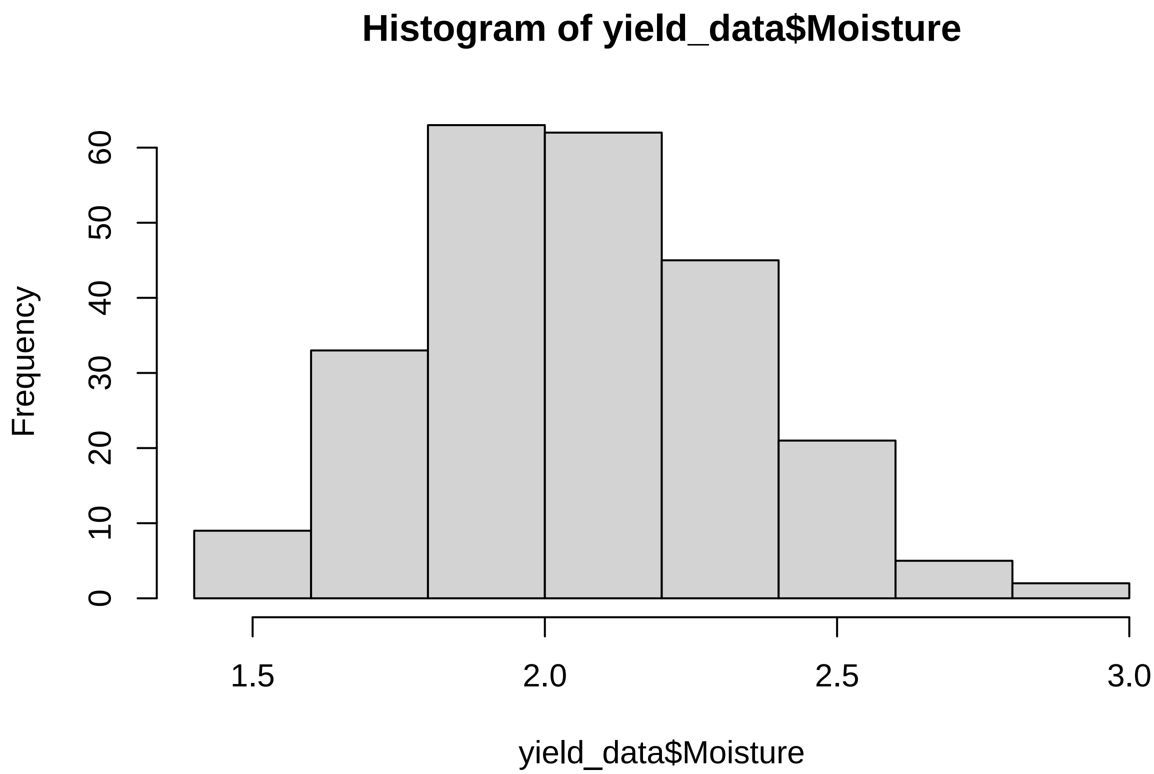

```
hist(yield_data$HarvestIndex)
```




```
boxplot(yield_data$Moisture)
```




```
hist(yield_data$Moisture)
```




```
#the data looks good - don't see any unusual values


yield_data <- dplyr::select(yield_data,
                            site_year,
                            year,
                            Block,
                            MainPlot,
                            SubPlot,
                            exp_plot_number,
                            N_level_kgha,
                            N_level_kgha_f,
                            TopDress_kgha,
                            TopDress_kgha_f,
                            GrainYield_Mgha
                            )


gs_data <- full_join(gs_ndvi_data , yield_data)
```

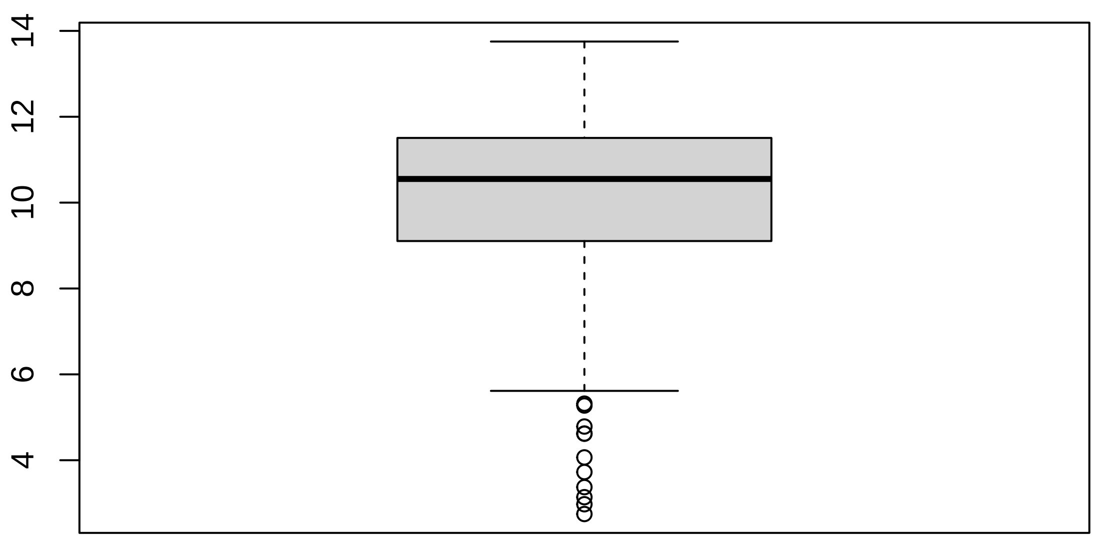
```
## Joining, by = c("site_year", "year", "exp_plot_number", "N_level_kgha")
```

```
gs_data <- dplyr::select(gs_data,
              site_year,
              year,
              exp_plot_number,
              Block,
              MainPlot,
              SubPlot,
              N_level_kgha,
```

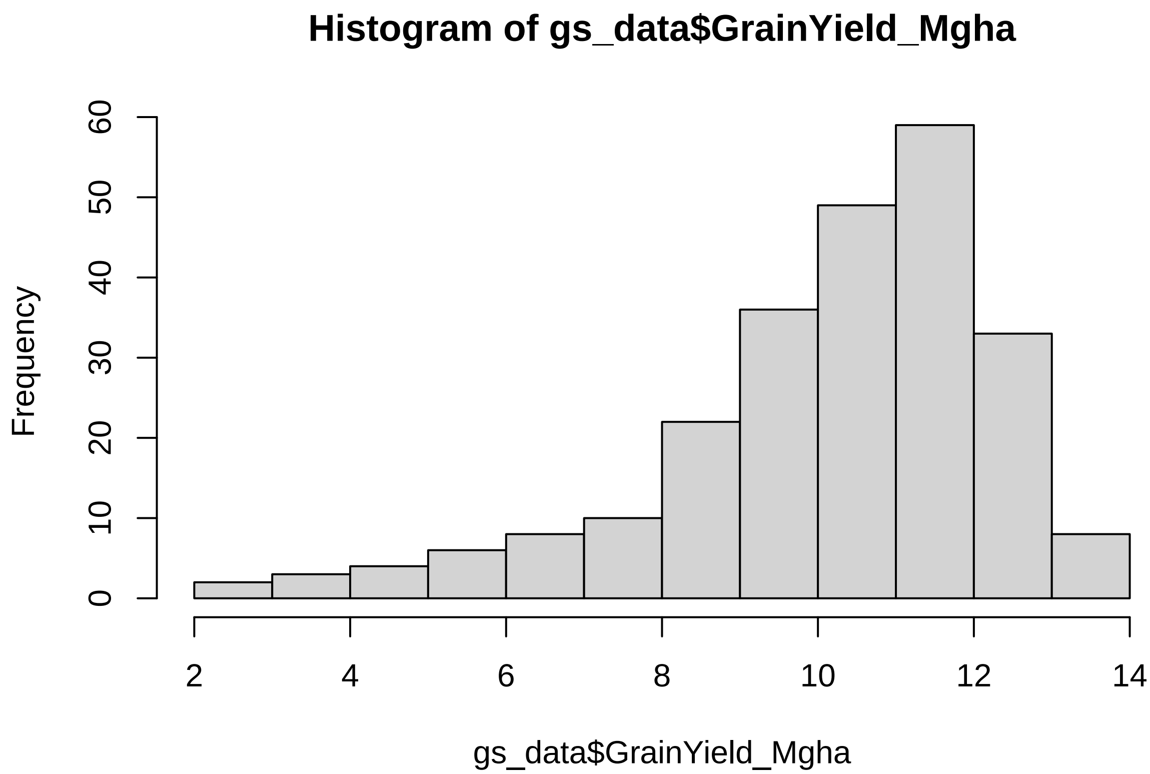
```r
               N_level_kgha_f,
               TopDress_kgha,
               TopDress_kgha_f ,
               PI_N_Uptake,
               NDVI,
               GrainYield_Mgha) #reorders the columns

gs_data$site_year <- as.factor(gs_data$site_year)

str(gs_data , give.attr = FALSE)
```

```
## rowwise_df [240 x 13] (S3: rowwise_df/tbl_df/tbl/data.frame)
##  $ site_year      : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year           : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number: Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block          : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot       : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ SubPlot        : Factor w/ 3 levels "1","2","3": 2 3 1 1 1 2 1 1 2 3 ...
##  $ N_level_kgha   : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ TopDress_kgha  : num [1:240] 0 0 0 0 0 0 0 0 0 0 ...
##  $ TopDress_kgha_f: Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ PI_N_Uptake    : num [1:240] 158 78 142 197 95 ...
##  $ NDVI           : num [1:240] 0.777 0.493 0.683 0.787 0.683 ...
##  $ GrainYield_Mgha: num [1:240] 11.4 11 12 11.9 11.5 ...
```

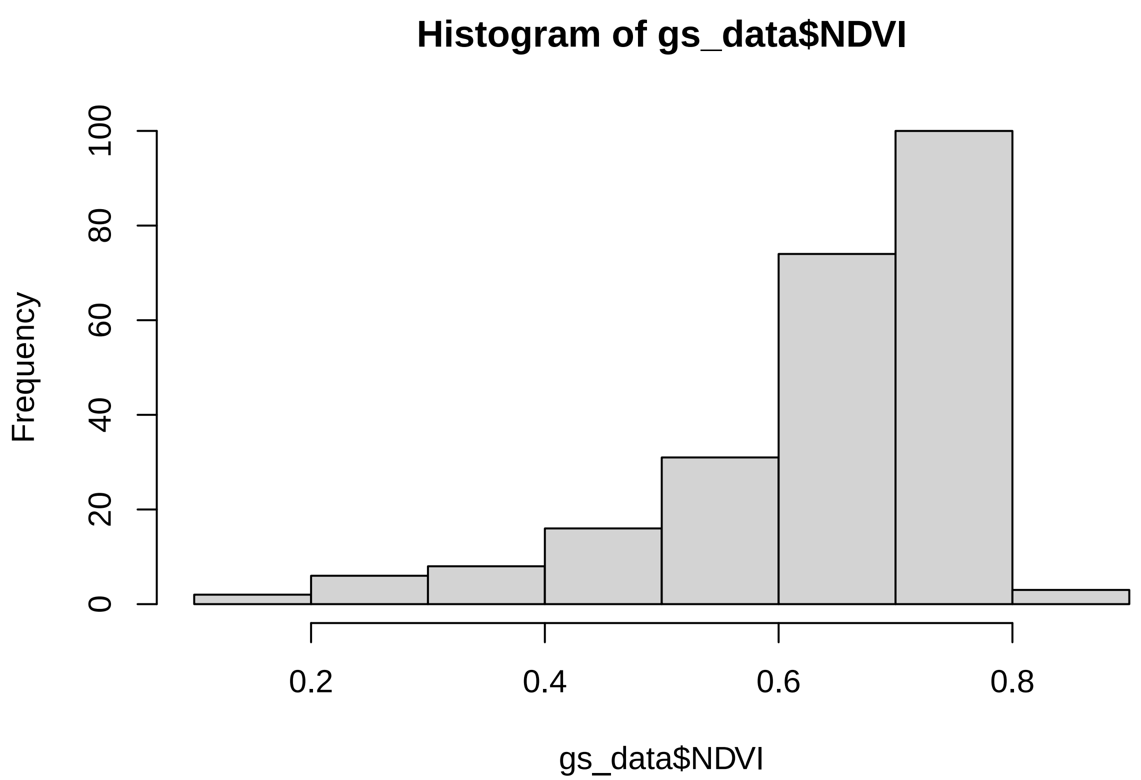
```r
boxplot(gs_data$GrainYield_Mgha)
```



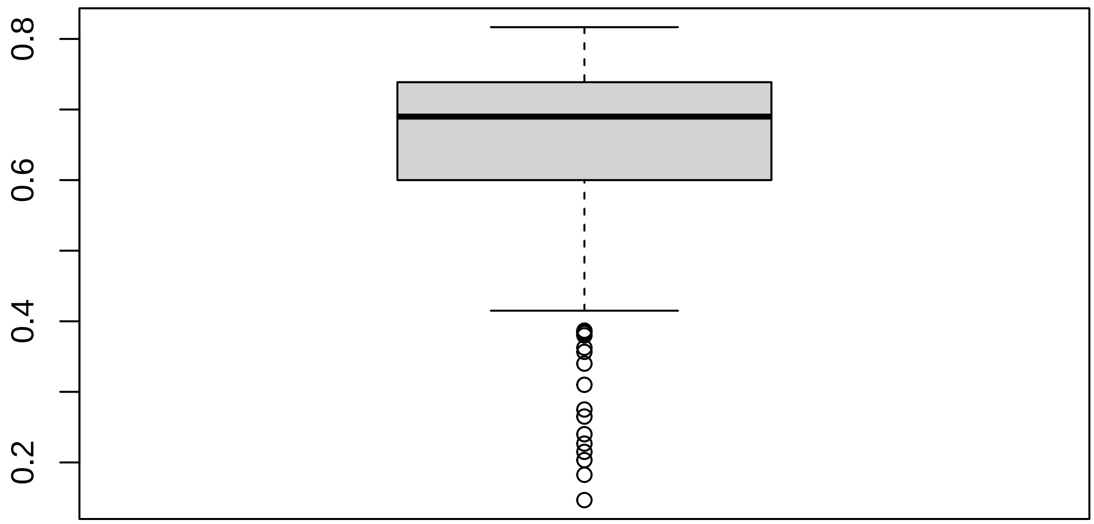

```r
hist(gs_data$GrainYield_Mgha)
```



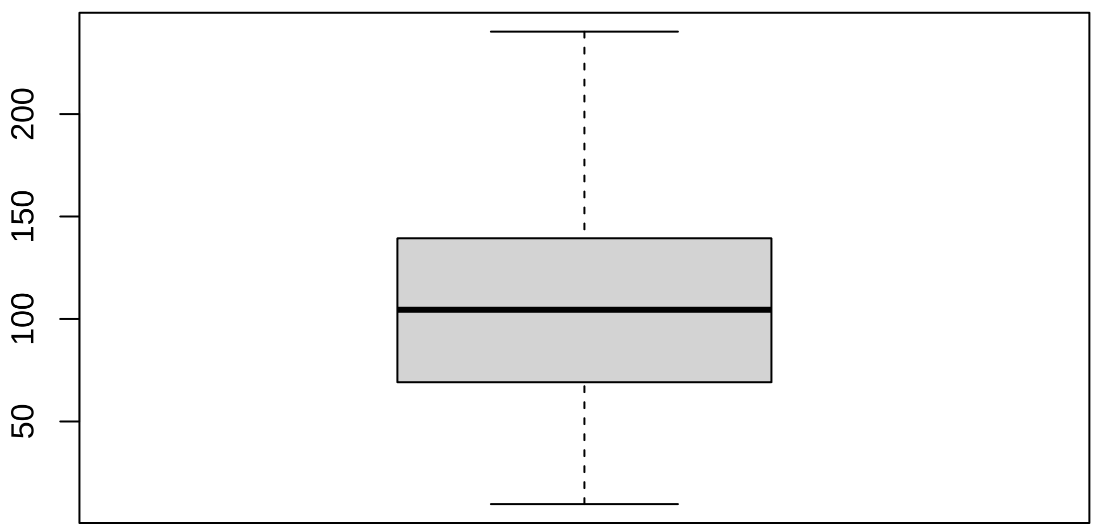

```
hist(gs_data$NDVI)
```



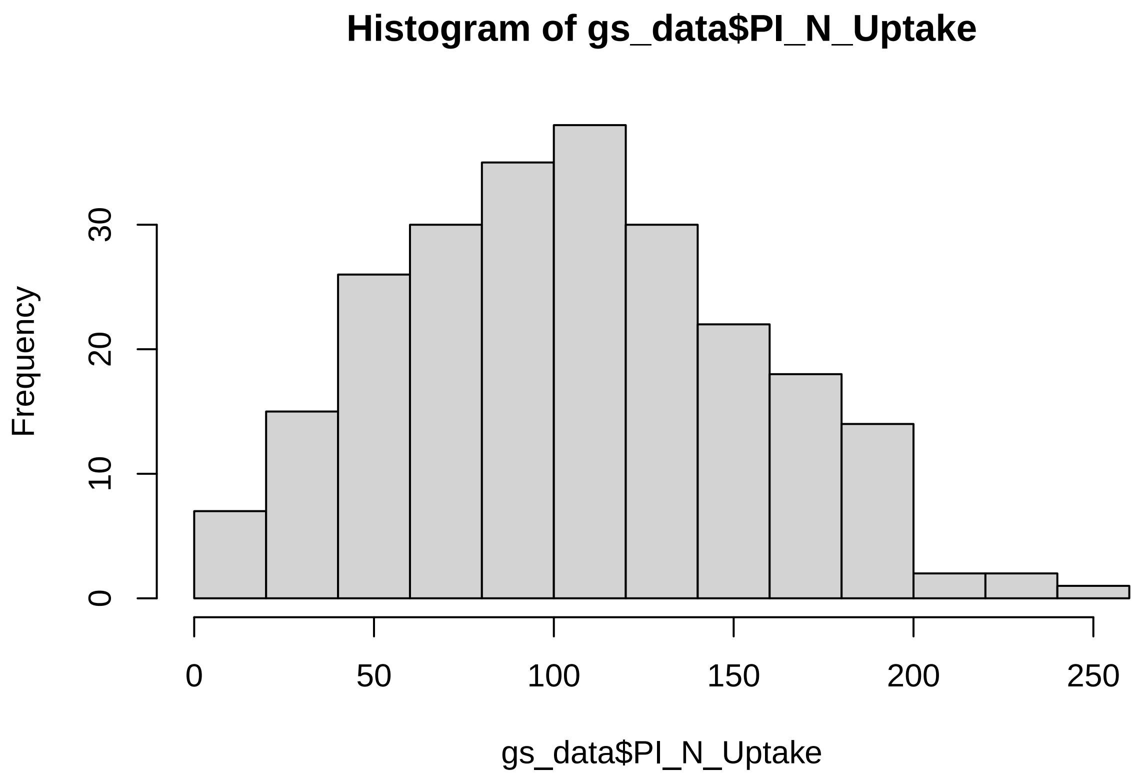

```
boxplot(gs_data$NDVI)
```




```
boxplot(gs_data$PI_N_Uptake)
```




```
hist(gs_data$PI_N_Uptake)
```




```
#Overall data looks good -- no errors of data entry
```

Calculating GS RI

```
max_gs_ndvi <- gs_data %>%
  filter(N_level_kgha_f %in% c(225, 235)) %>%
  dplyr::select(site_year , NDVI) %>%
  group_by(site_year) %>%
  summarise(mean_NDVI = mean(NDVI))

nic17 <- subset(max_gs_ndvi, site_year == "Nicolaus-17")
nic17maxNDVI <- nic17$mean_NDVI
nic17maxNDVI <- as.numeric(nic17maxNDVI)
nic17maxNDVI
```

```
## [1] 0.7858333
```

```
wil17 <- subset(max_gs_ndvi, site_year == "Williams-17")
wil17maxNDVI <- wil17$mean_NDVI
wil17maxNDVI <- as.numeric(wil17maxNDVI)
wil17maxNDVI
```

```
## [1] 0.7925
```

```
arb18 <- subset(max_gs_ndvi, site_year == "Arbuckle-18")
arb18maxNDVI <- arb18$mean_NDVI
arb18maxNDVI <- as.numeric(arb18maxNDVI)
arb18maxNDVI
```

```
## [1] 0.73875
```

```r
biggs18 <- subset(max_gs_ndvi, site_year == "Biggs-18")
biggs18maxNDVI <- biggs18$mean_NDVI
biggs18maxNDVI <- as.numeric(biggs18maxNDVI)
biggs18maxNDVI
```

```
## [1] 0.784375
```

```r
mry18 <- subset(max_gs_ndvi, site_year == "Marysville-18")
mry18maxNDVI <- mry18$mean_NDVI
mry18maxNDVI <- as.numeric(mry18maxNDVI)
mry18maxNDVI
```

```
## [1] 0.728125
```

```r
nic18 <- subset(max_gs_ndvi, site_year == "Nicolaus-18")
nic18maxNDVI <- nic18$mean_NDVI
nic18maxNDVI <- as.numeric(nic18maxNDVI)
nic18maxNDVI
```

```
## [1] 0.765
```

```r
arb19 <- subset(max_gs_ndvi, site_year == "Arbuckle-19")
arb19maxNDVI <- arb19$mean_NDVI
arb19maxNDVI <- as.numeric(arb19maxNDVI)
arb19maxNDVI
```

```
## [1] 0.72
```

```r
davis19 <- subset(max_gs_ndvi, site_year == "Davis-19")
davis19maxNDVI <- davis19$mean_NDVI
davis19maxNDVI <- as.numeric(davis19maxNDVI)
davis19maxNDVI
```

```
## [1] 0.613125
```

```r
mry19 <- subset(max_gs_ndvi, site_year == "Marysville-19")
mry19maxNDVI <- mry19$mean_NDVI
mry19maxNDVI <- as.numeric(mry19maxNDVI)
mry19maxNDVI
```

```
## [1] 0.745625
```

```r
res19 <- subset(max_gs_ndvi, site_year == "RES-19")
res19maxNDVI <- res19$mean_NDVI
res19maxNDVI <- as.numeric(res19maxNDVI)
res19maxNDVI
```

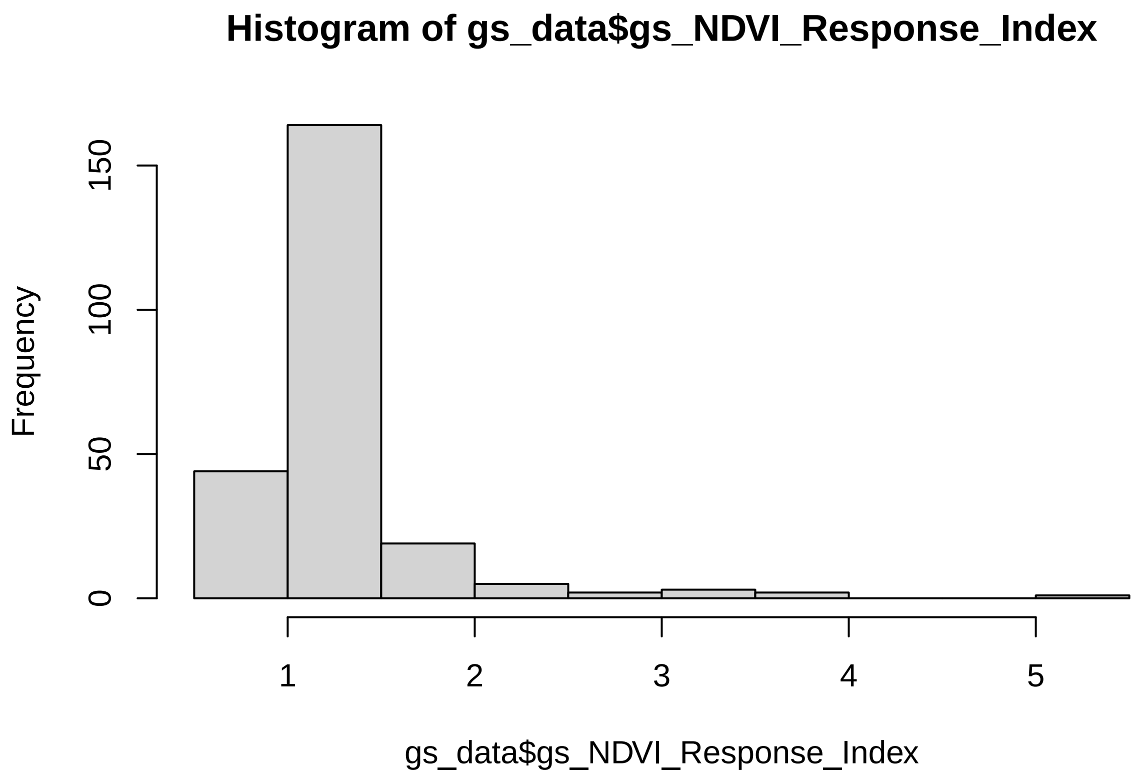
```
## [1] 0.66625
```

```r
gs_data <- gs_data %>%
  mutate(max_NDVI = case_when(
                          site_year == "Nicolaus-17" ~ nic17maxNDVI ,
                          site_year == "Williams-17" ~ wil17maxNDVI ,
                          site_year == "Arbuckle-18" ~ arb18maxNDVI ,
                          site_year == "Biggs-18" ~ biggs18maxNDVI ,
                          site_year == "Marysville-18" ~ mry18maxNDVI ,
                          site_year == "Nicolaus-18" ~ nic18maxNDVI,
                          site_year == "Arbuckle-19" ~ arb19maxNDVI ,
                          site_year == "Davis-19" ~ davis19maxNDVI ,
```

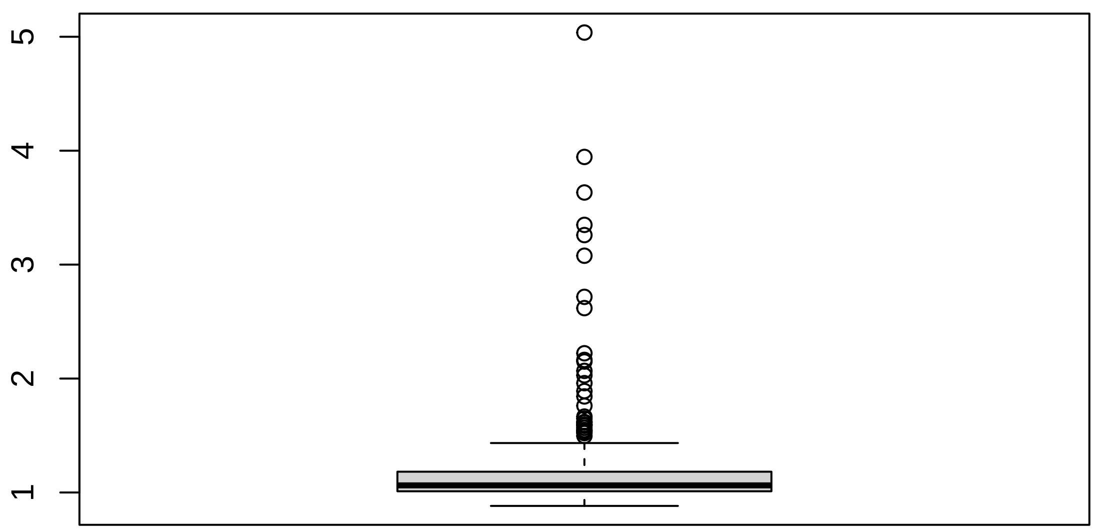
```r
                          site_year == "Marysville-19" ~ mry19maxNDVI ,
                          site_year == "RES-19" ~ res19maxNDVI)
  )

gs_data <- gs_data %>%
  mutate(gs_NDVI_Response_Index = case_when(
                          site_year == "Nicolaus-17" ~ nic17maxNDVI / NDVI,
                          site_year == "Williams-17" ~ wil17maxNDVI / NDVI,
                          site_year == "Arbuckle-18" ~ arb18maxNDVI / NDVI ,
                          site_year == "Biggs-18" ~ biggs18maxNDVI / NDVI ,
                          site_year == "Marysville-18" ~ mry18maxNDVI / NDVI ,
                          site_year == "Nicolaus-18" ~ nic18maxNDVI / NDVI,
                          site_year == "Arbuckle-19" ~ arb19maxNDVI / NDVI,
                          site_year == "Davis-19" ~ davis19maxNDVI / NDVI,
                          site_year == "Marysville-19" ~ mry19maxNDVI / NDVI,
                          site_year == "RES-19" ~ res19maxNDVI / NDVI
                        )) #calculates NDVI response index

str(gs_data , give.attr = FALSE)
```

```
## rowwise_df [240 x 15] (S3: rowwise_df/tbl_df/tbl/data.frame)
##  $ site_year             : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year                  : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number       : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block                 : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot              : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ SubPlot               : Factor w/ 3 levels "1","2","3": 2 3 1 1 1 2 1 1 2 3 ...
##  $ N_level_kgha          : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f        : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ TopDress_kgha         : num [1:240] 0 0 0 0 0 0 0 0 0 0 ...
##  $ TopDress_kgha_f       : Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ PI_N_Uptake           : num [1:240] 158 78 142 197 95 ...
##  $ NDVI                  : num [1:240] 0.777 0.493 0.683 0.787 0.683 ...
##  $ GrainYield_Mgha       : num [1:240] 11.4 11 12 11.9 11.5 ...
##  $ max_NDVI              : num [1:240] 0.786 0.786 0.786 0.786 0.786 ...
##  $ gs_NDVI_Response_Index: num [1:240] 1.012 1.593 1.15 0.999 1.15 ...
```

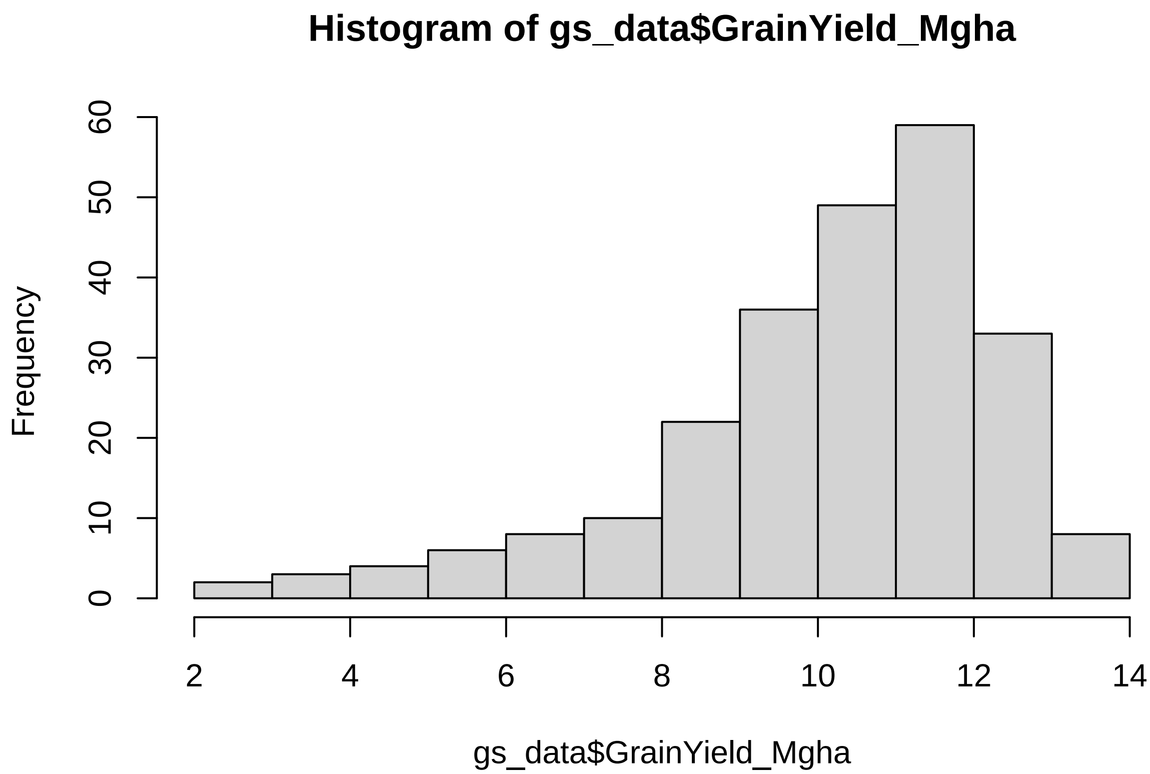
```r
hist(gs_data$gs_NDVI_Response_Index)
```



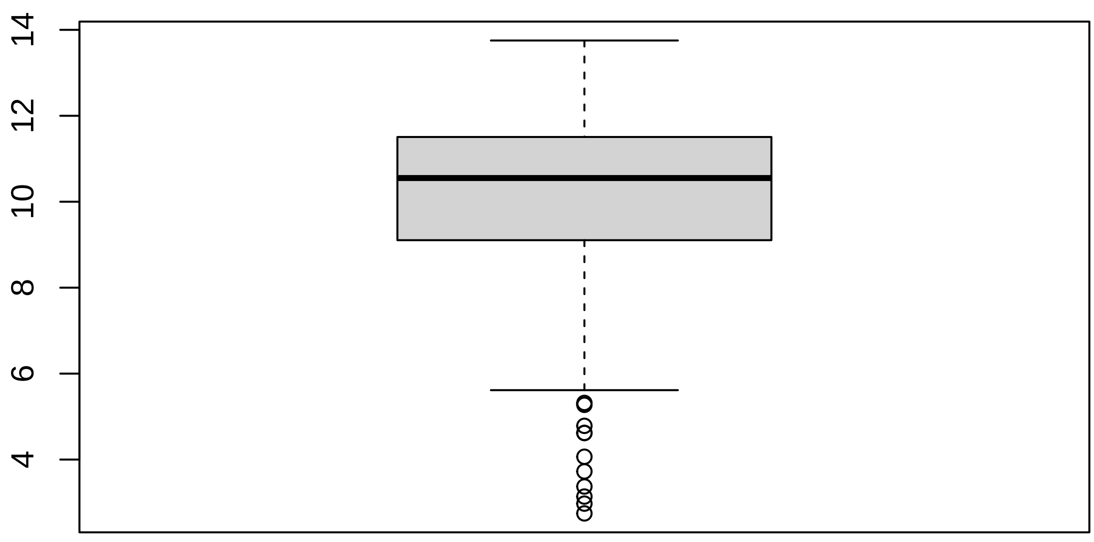

```
boxplot(gs_data$gs_NDVI_Response_Index)
```




```
hist(gs_data$GrainYield_Mgha)
```




```
boxplot(gs_data$GrainYield_Mgha)
```



Drone Data

```
drone_data <- read_csv(file = "DATA/PI_drone_data.csv")
```

```
## Rows: 248 Columns: 38
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr  (1): site_year
## dbl (37): year, exp_plot_number, Block, MainPlot, N_level, N_level_kgha, bio...
##
```

```
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
str(drone_data , give.attr = FALSE)
```

```
## spec_tbl_df [248 x 38] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ site_year         : chr [1:248] "Nicolaus-17" "Nicolaus-17" "Nicolaus-17" "Nicolaus-17" ...
##  $ year              : num [1:248] 2017 2017 2017 2017 2017 ...
##  $ exp_plot_number   : num [1:248] 101 102 103 104 105 106 107 201 202 203 ...
##  $ Block             : num [1:248] 1 1 1 1 1 1 1 2 2 2 ...
##  $ MainPlot          : num [1:248] 1 2 3 4 5 6 7 1 2 3 ...
##  $ N_level           : num [1:248] 225 0 125 175 275 45 75 275 75 125 ...
##  $ N_level_kgha      : num [1:248] 225 0 125 175 275 45 75 275 75 125 ...
##  $ biomass_plus_bag_g: num [1:248] 361 264 318 360 394 ...
##  $ ring_size         : num [1:248] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ paper_bag_g       : num [1:248] 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 ...
##  $ num_of_paper_bags : num [1:248] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg  : num [1:248] 3.17 3.42 3.09 3.07 3.35 ...
##  $ sample_N_ug       : num [1:248] 79.4 61.1 80.7 95.9 111.3 ...
##  $ greenmean         : num [1:248] 0.0467 0.0581 0.0498 0.0488 0.0505 0.0608 0.0589 0.0461 0.0537 0.0
##  $ greenmedia        : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenstdev        : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenmin          : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenmax          : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemean          : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemedian        : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluestdev         : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemin           : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemax           : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ redmean           : num [1:248] 0.023 0.0286 0.0243 0.0237 0.0245 0.0292 0.0281 0.0234 0.0263 0.0
##  $ redmedian         : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ redstdev          : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ redmin            : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ redmax            : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgemean          : num [1:248] 0.0738 0.0867 0.0768 0.0764 0.0791 0.0903 0.0877 0.0744 0.0812 0.0
##  $ edgemedian        : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgestdev         : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgemin           : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgemax           : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirmean           : num [1:248] 0.55 0.357 0.482 0.537 0.599 ...
##  $ nirmedian         : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirstdev          : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirmin            : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirmax            : num [1:248] NA NA NA NA NA NA NA NA NA NA ...
```

```r
drone_data <- drone_data %>%
  filter(N_level_kgha != 275) %>%
  mutate(year = factor(year) ,
         exp_plot_number = factor(exp_plot_number) ,
         Block = factor(Block) ,
         MainPlot = factor(MainPlot) ,
         N_level = factor(N_level) ,
         N_level_kgha_f = factor(N_level_kgha)
  )
```

```
drone_data$site_year <- factor(drone_data$site_year , levels = c("Nicolaus-17" , "Williams-17" , "Arbuc

str(drone_data , give.attr = FALSE)
```

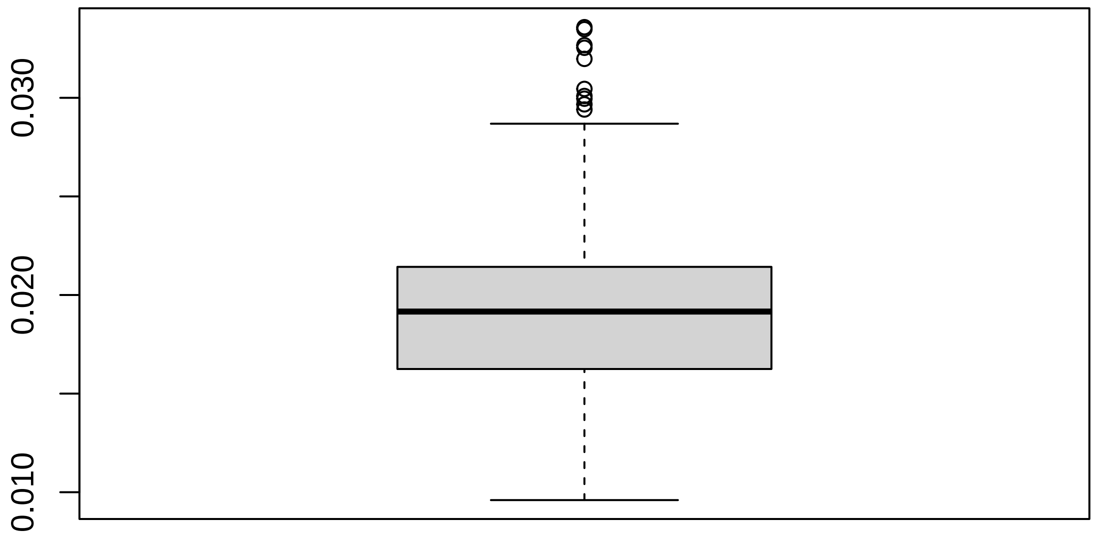
```
## tibble [240 x 39] (S3: tbl_df/tbl/data.frame)
##  $ site_year          : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year               : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number    : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block              : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot           : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ N_level            : Factor w/ 11 levels "0","45","75",..: 11 1 6 8 2 3 3 6 1 8 ...
##  $ N_level_kgha       : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ biomass_plus_bag_g: num [1:240] 361 264 318 360 285 ...
##  $ ring_size          : num [1:240] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ paper_bag_g        : num [1:240] 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 ...
##  $ num_of_paper_bags : num [1:240] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg   : num [1:240] 3.17 3.42 3.09 3.07 3.2 ...
##  $ sample_N_ug        : num [1:240] 79.4 61.1 80.7 95.9 63.6 ...
##  $ greenmean          : num [1:240] 0.0467 0.0581 0.0498 0.0488 0.0608 0.0589 0.0537 0.0488 0.0598 0.0
##  $ greenmedia         : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenstdev         : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenmin           : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenmax           : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemean           : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemedian         : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluestdev          : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemin            : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ bluemax            : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ redmean            : num [1:240] 0.023 0.0286 0.0243 0.0237 0.0292 0.0281 0.0263 0.0237 0.0293 0.0
##  $ redmedian          : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ redstdev           : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ redmin             : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ redmax             : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgemean           : num [1:240] 0.0738 0.0867 0.0768 0.0764 0.0903 0.0877 0.0812 0.0754 0.0873 0.0
##  $ edgemedian         : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgestdev          : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgemin            : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ edgemax            : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirmean            : num [1:240] 0.55 0.357 0.482 0.537 0.431 ...
##  $ nirmedian          : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirstdev           : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirmin             : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ nirmax             : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ N_level_kgha_f     : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
```

```
drone_data <- dplyr::select(drone_data ,
                      site_year,
                      year,
                      exp_plot_number,
                      Block,
                      MainPlot,
                      N_level,
                      N_level_kgha,
                      N_level_kgha_f,
```

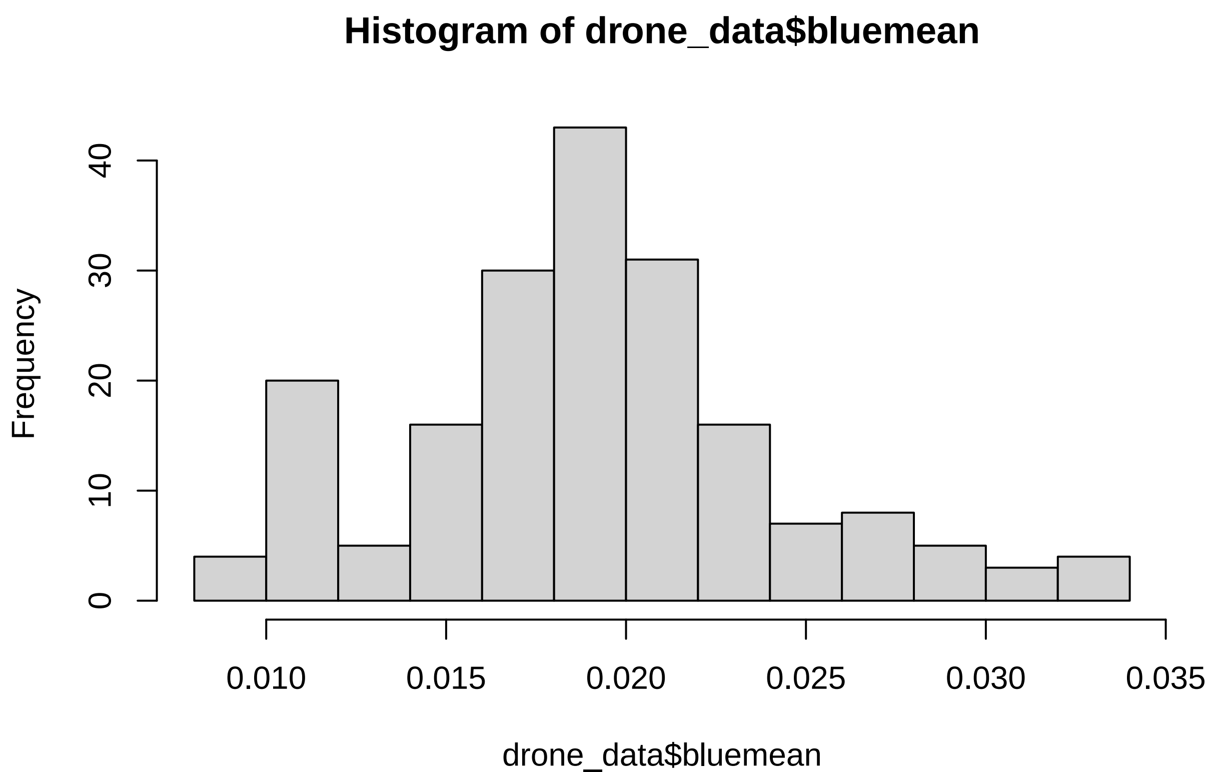
```r
                      biomass_plus_bag_g,
                      ring_size,
                      paper_bag_g,
                      num_of_paper_bags,
                      sample_weight_mg,
                      sample_N_ug,
                      bluemean,
                      greenmean,
                      redmean,
                      edgemean,
                      nirmean
                      )#selects the relevant columns

str(drone_data , give.attr = FALSE)
```

```
## tibble [240 x 19] (S3: tbl_df/tbl/data.frame)
##  $ site_year         : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year              : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number   : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block             : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot          : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ N_level           : Factor w/ 11 levels "0","45","75",..: 11 1 6 8 2 3 3 6 1 8 ...
##  $ N_level_kgha      : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f    : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ biomass_plus_bag_g: num [1:240] 361 264 318 360 285 ...
##  $ ring_size         : num [1:240] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ paper_bag_g       : num [1:240] 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 ...
##  $ num_of_paper_bags : num [1:240] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg  : num [1:240] 3.17 3.42 3.09 3.07 3.2 ...
##  $ sample_N_ug       : num [1:240] 79.4 61.1 80.7 95.9 63.6 ...
##  $ bluemean          : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenmean         : num [1:240] 0.0467 0.0581 0.0498 0.0488 0.0608 0.0589 0.0537 0.0488 0.0598 0.0
##  $ redmean           : num [1:240] 0.023 0.0286 0.0243 0.0237 0.0292 0.0281 0.0263 0.0237 0.0293 0.0
##  $ edgemean          : num [1:240] 0.0738 0.0867 0.0768 0.0764 0.0903 0.0877 0.0812 0.0754 0.0873 0.0
##  $ nirmean           : num [1:240] 0.55 0.357 0.482 0.537 0.431 ...
```

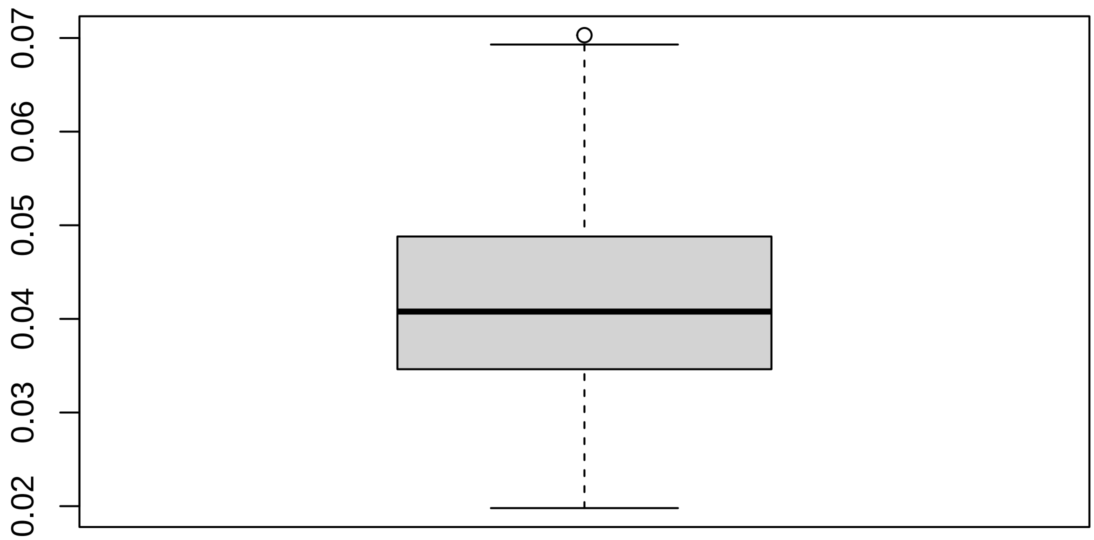
```r
#visualize drone_data to look for outliers

boxplot(drone_data$bluemean)
```



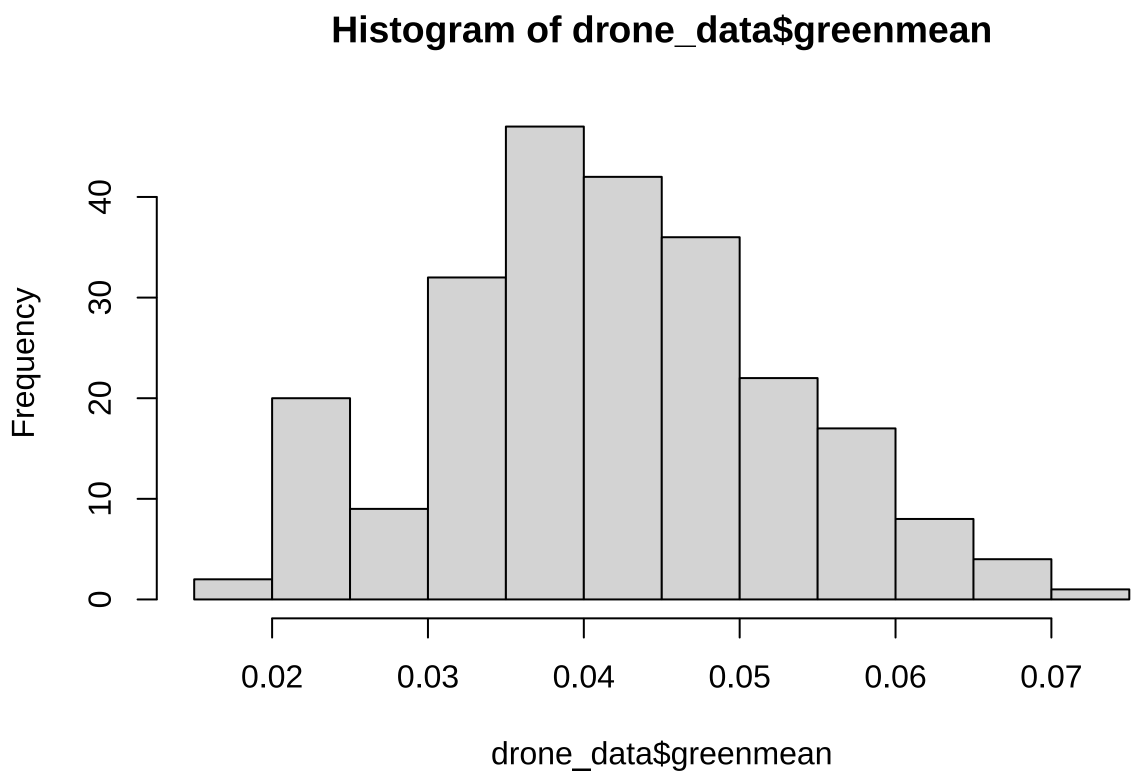

```
hist(drone_data$bluemean)
```



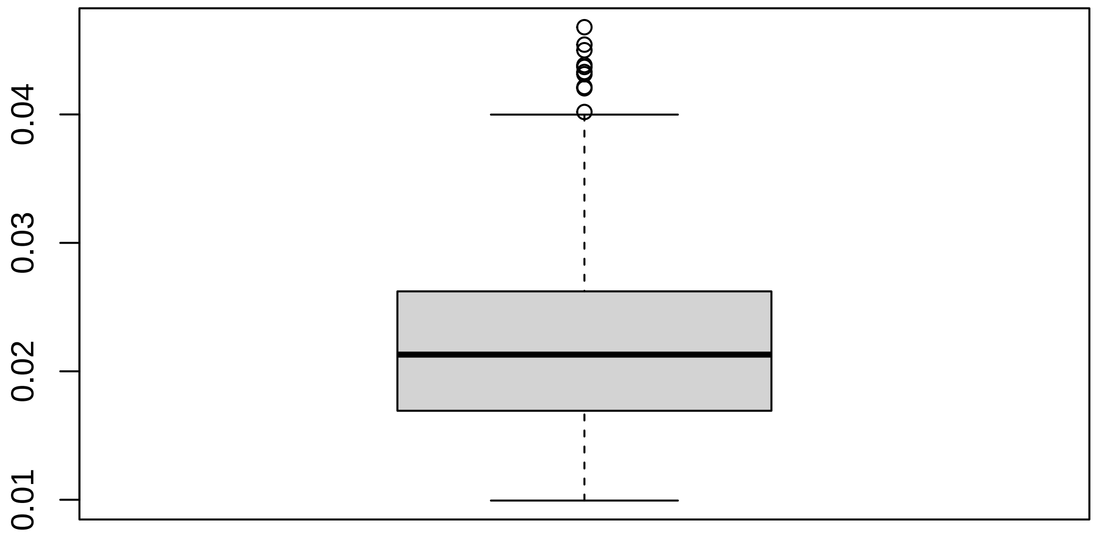

```
boxplot(drone_data$greenmean)
```



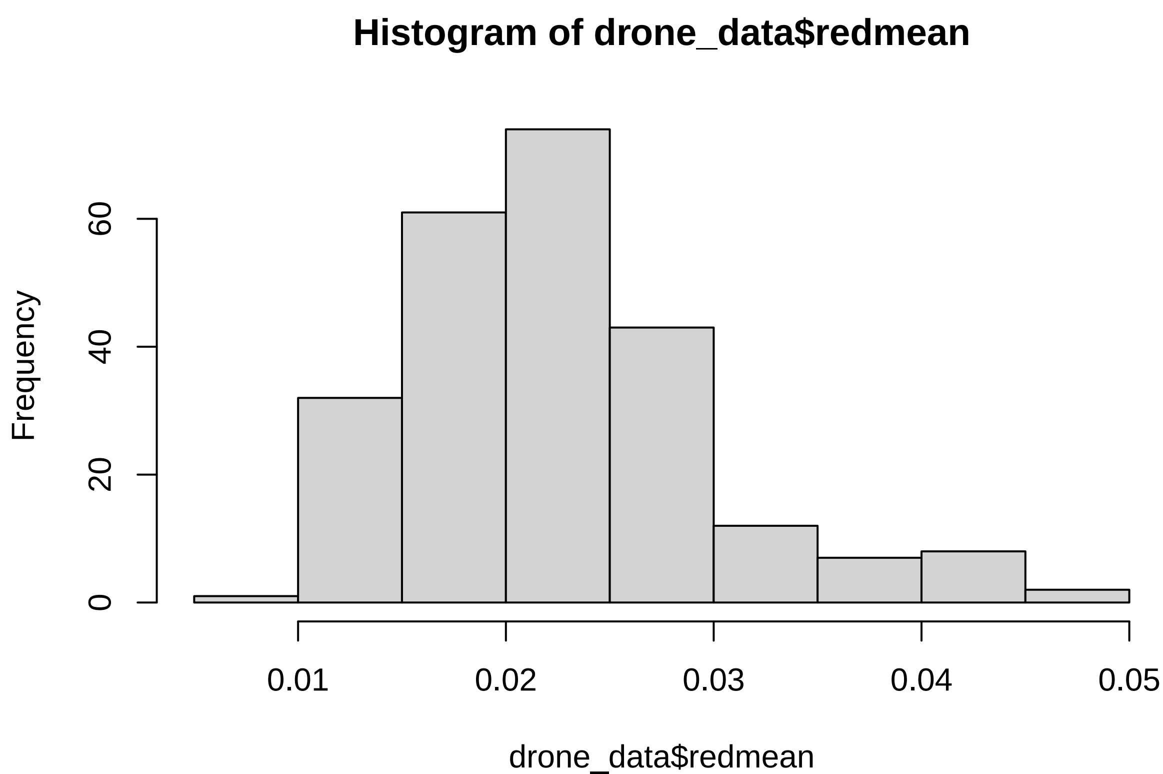

```
hist(drone_data$greenmean)
```



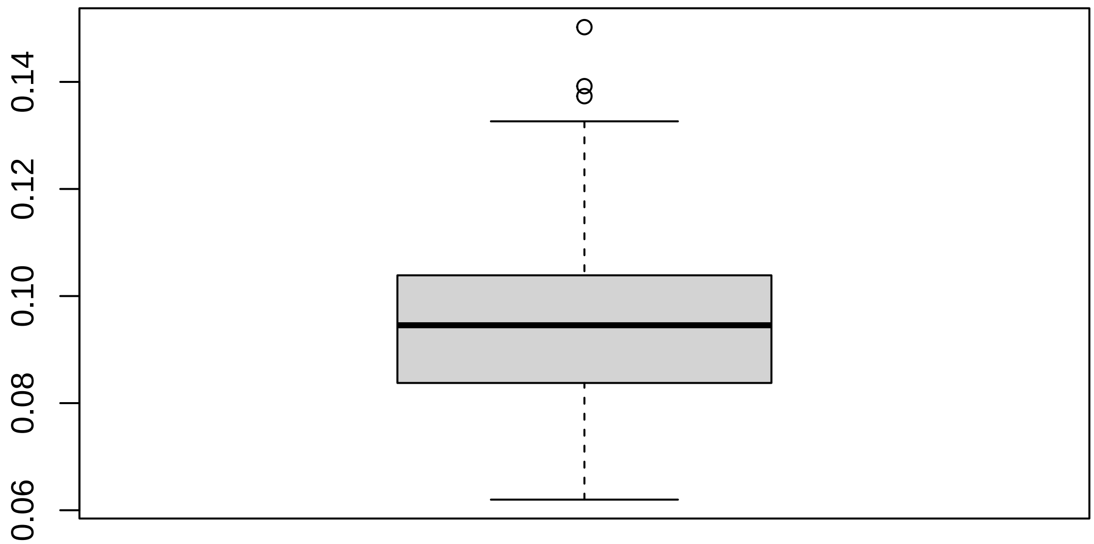

```
boxplot(drone_data$redmean)
```



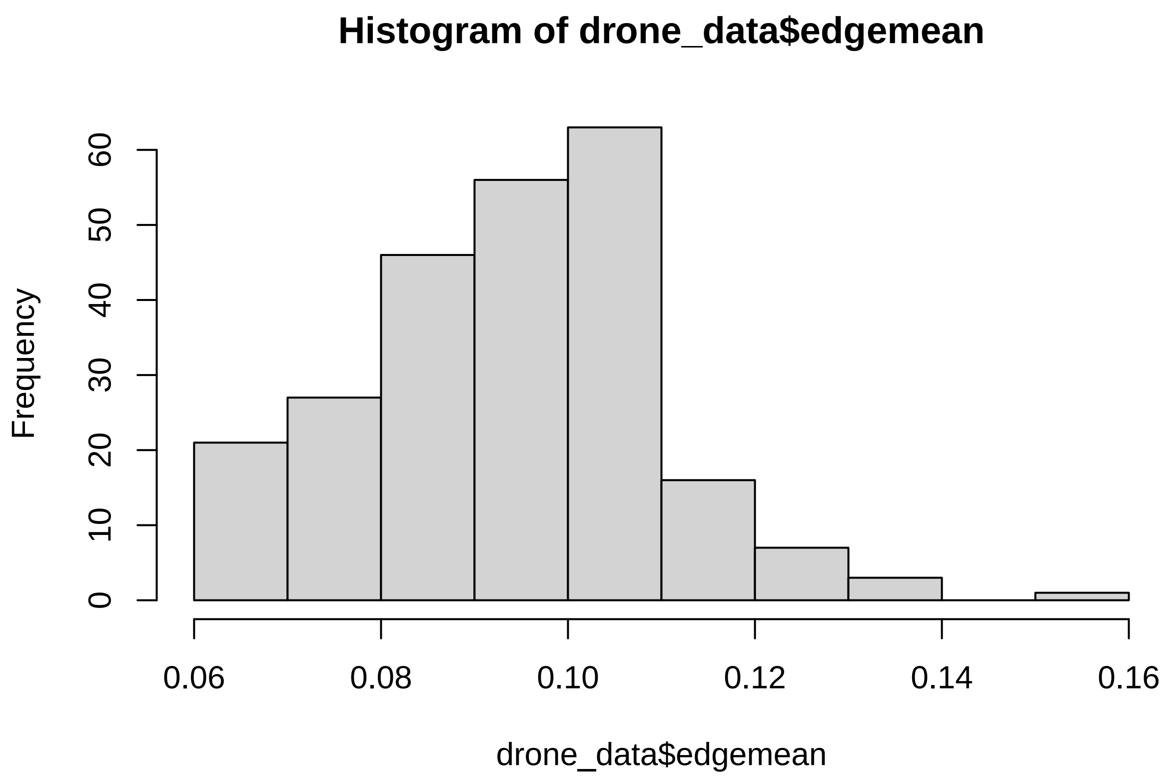

```
hist(drone_data$redmean)
```



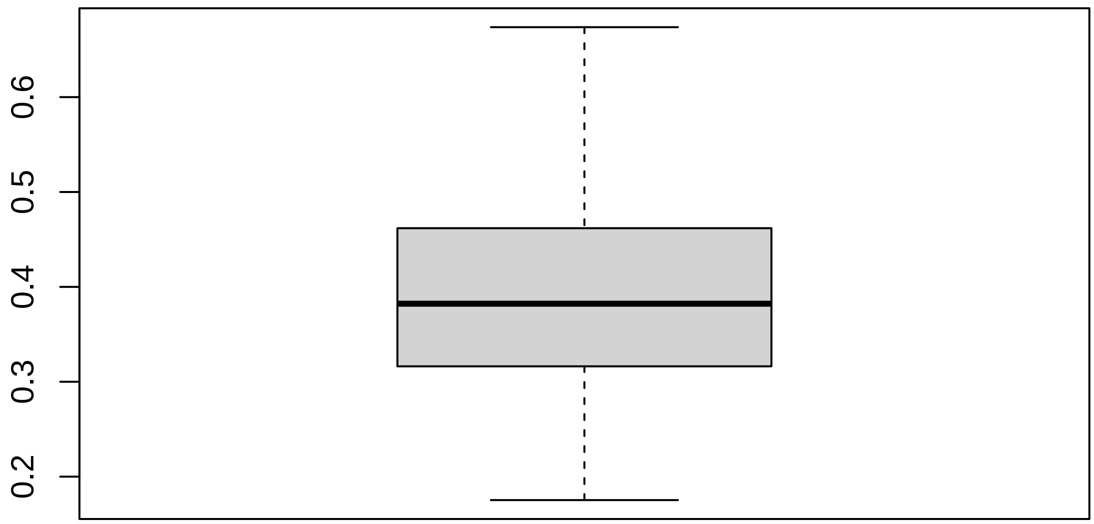

```
boxplot(drone_data$edgemean)
```



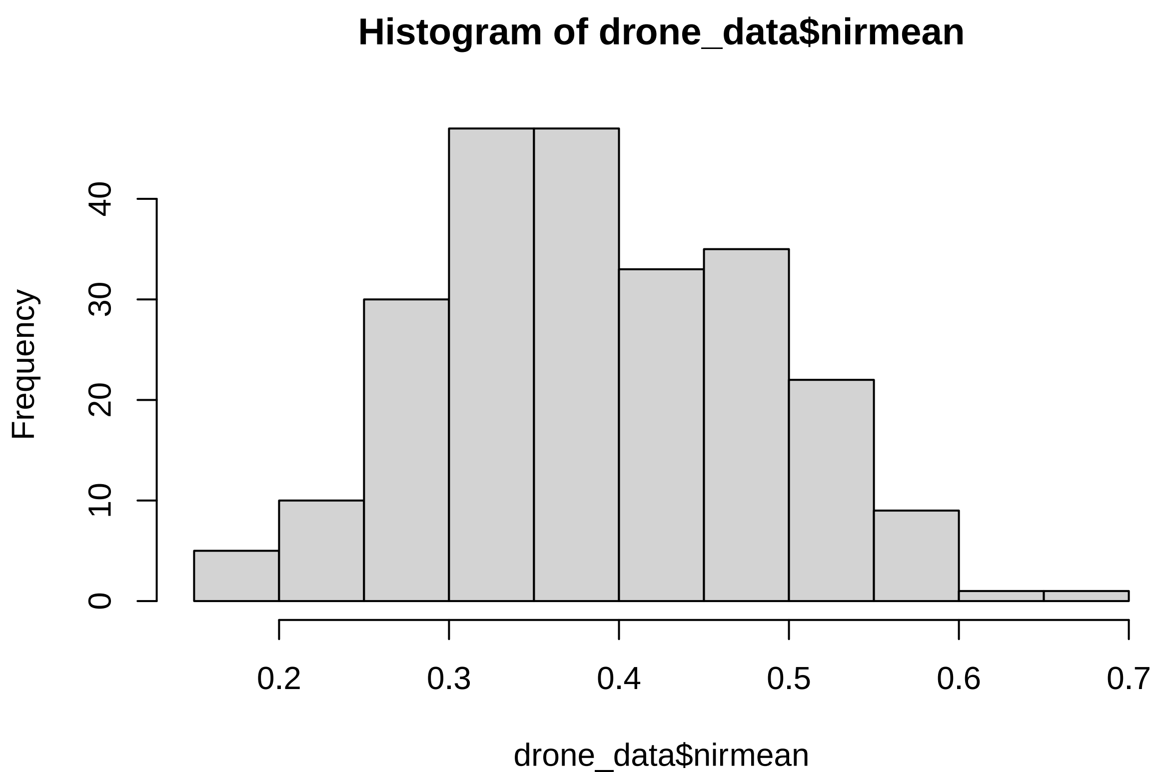

```
hist(drone_data$edgemean)
```



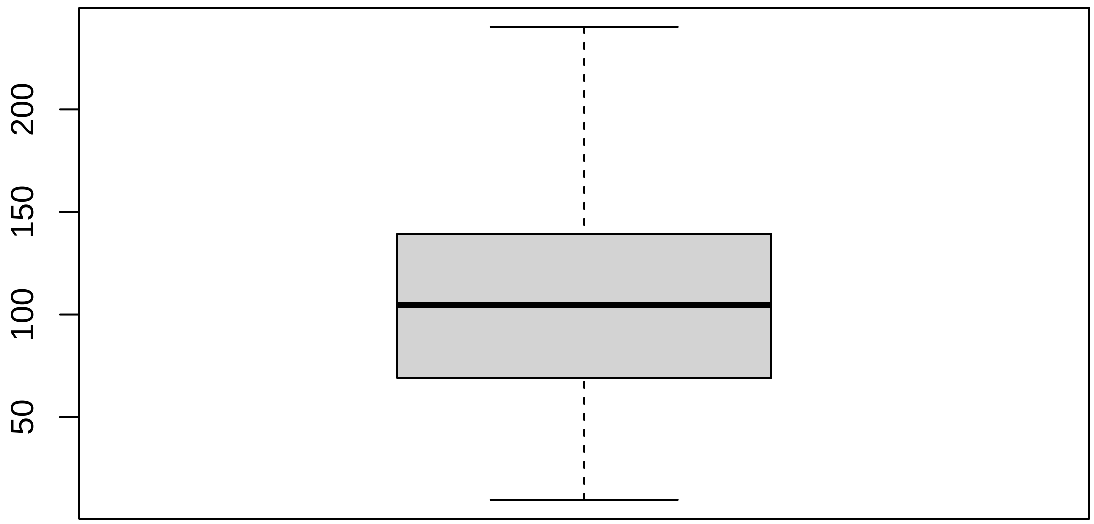

```
boxplot(drone_data$nirmean)
```



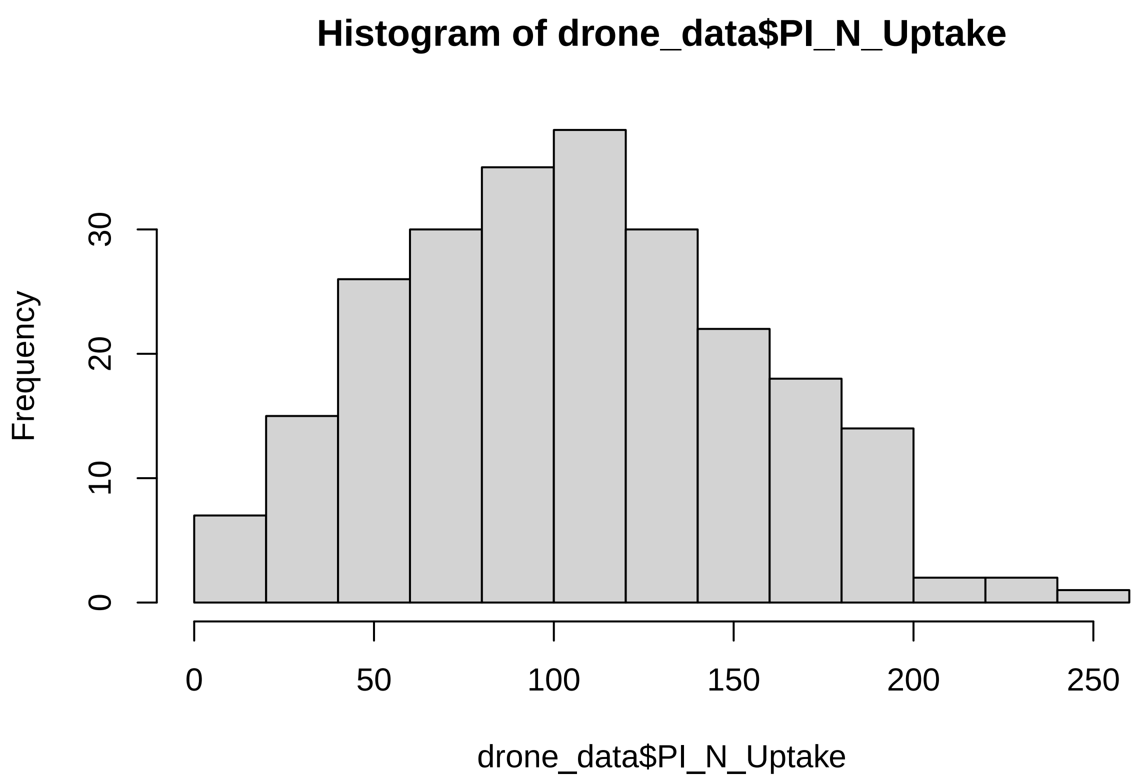

```
hist(drone_data$nirmean)
```



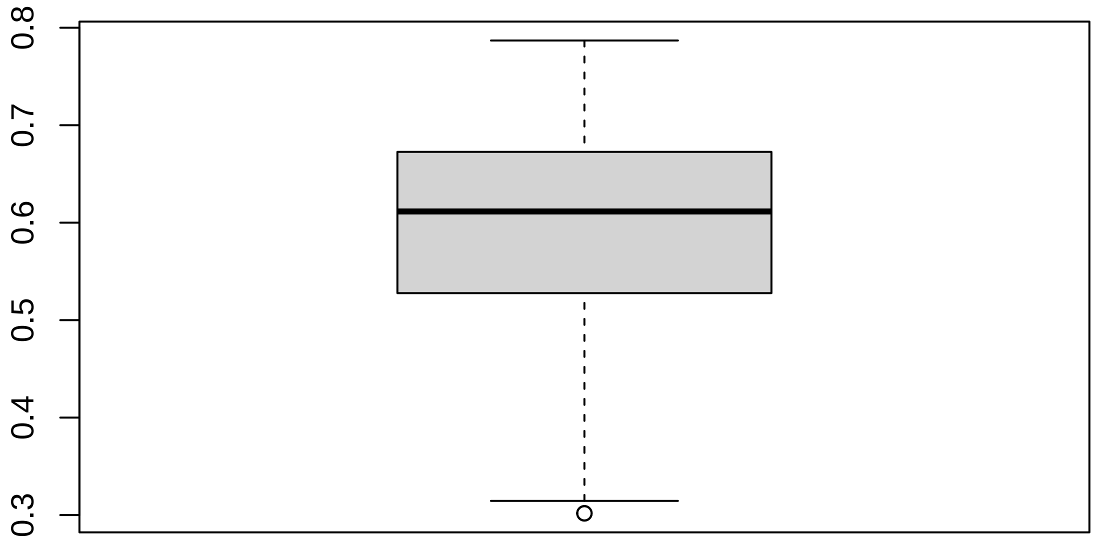

```
drone_data <-  drone_data %>%
  mutate( biomass_dry_wt = biomass_plus_bag_g - (paper_bag_g * num_of_paper_bags) ,
          aboveground_biomass = (biomass_dry_wt / ring_size) * 10 , #ring size 0.5 m^2 biomass in kg pe
          n_content = sample_N_ug / sample_weight_mg ,
          PI_N_Uptake = (aboveground_biomass * n_content) / 1000 #n uptake in kg per ha
          )#processes the data2

boxplot(drone_data$PI_N_Uptake)
```



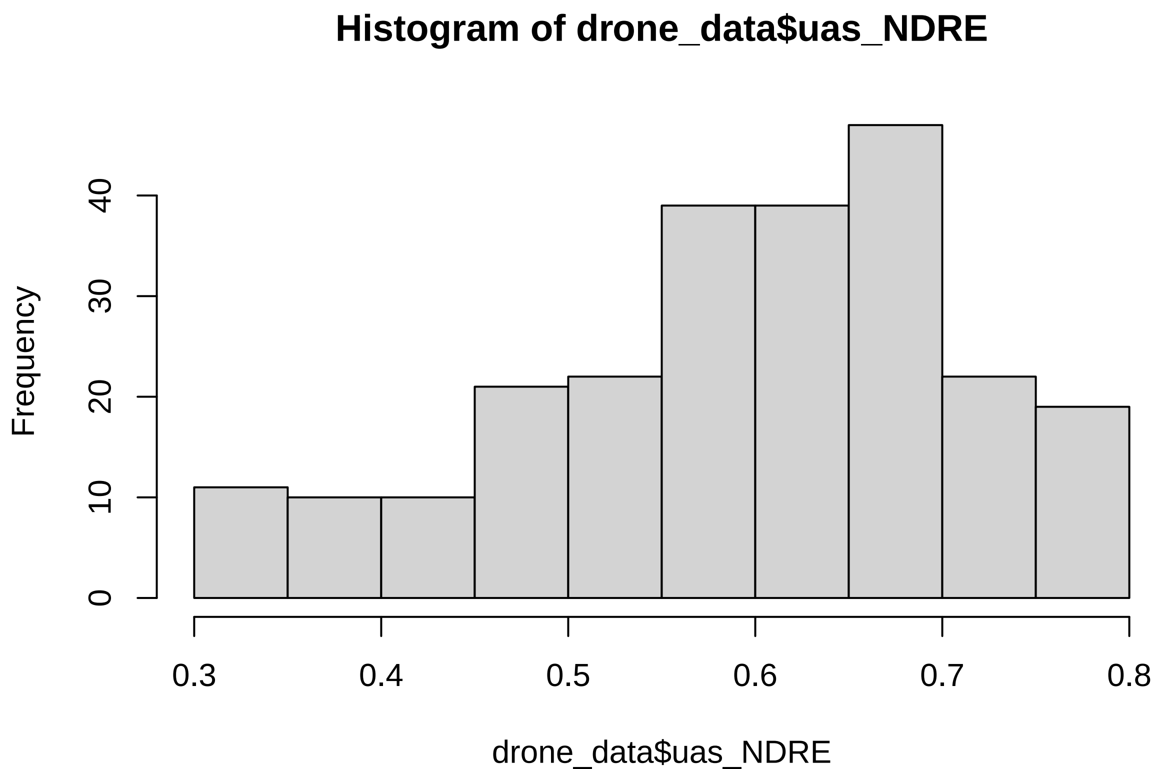

```
hist(drone_data$PI_N_Uptake)
```



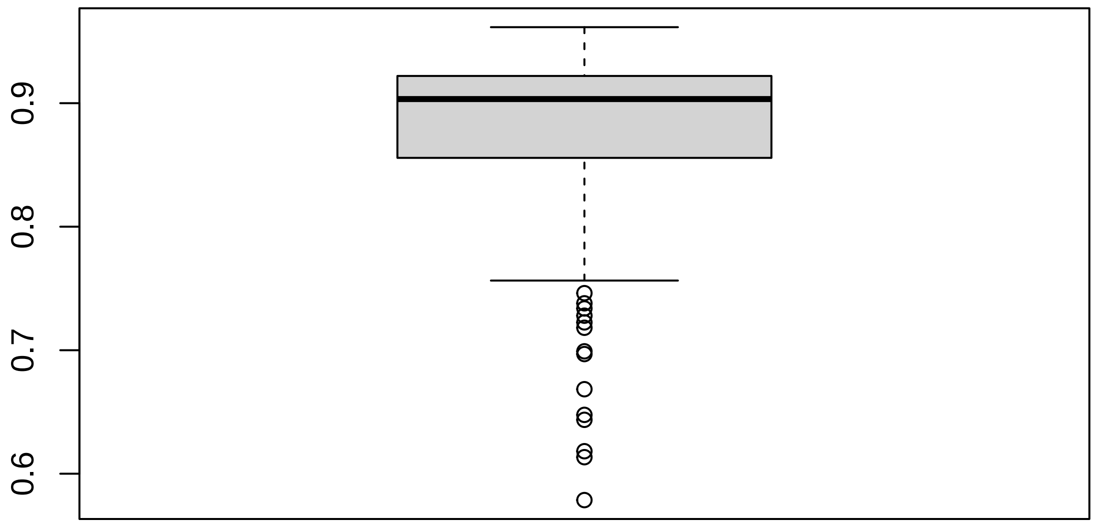

```
drone_data <- drone_data %>%
  mutate(uas_NDRE = ((nirmean - edgemean) / (nirmean + edgemean)) ,
         uas_NDVI = ((nirmean - redmean) / (nirmean + redmean))
         ) #calculates NDRE and NDVI

boxplot(drone_data$uas_NDRE)
```



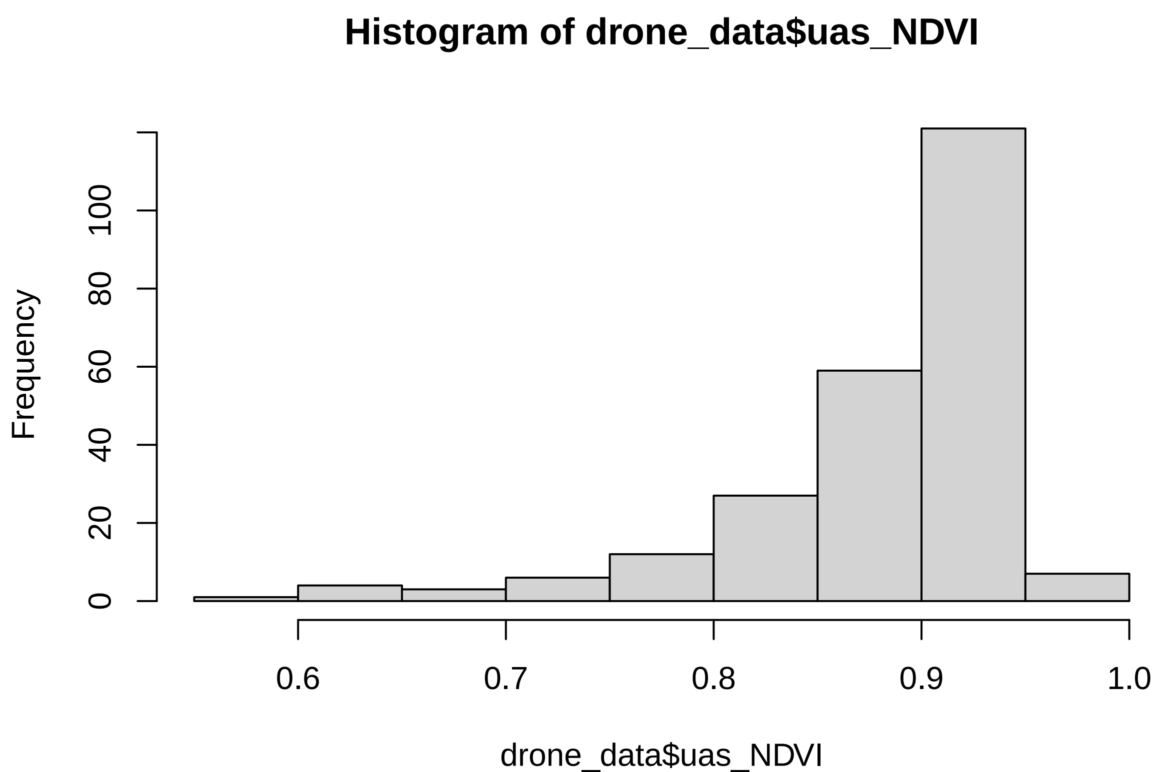

```
hist(drone_data$uas_NDRE)
```



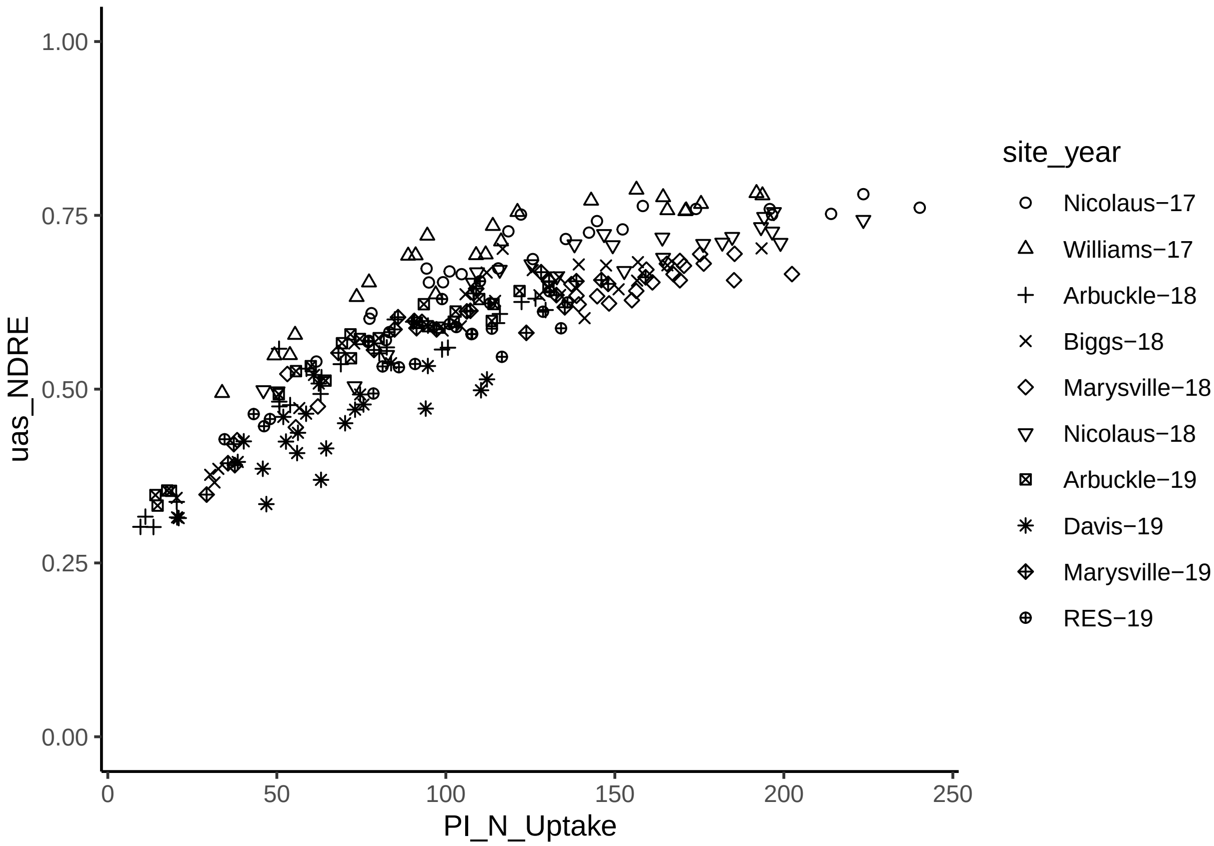

```
boxplot(drone_data$uas_NDVI)
```



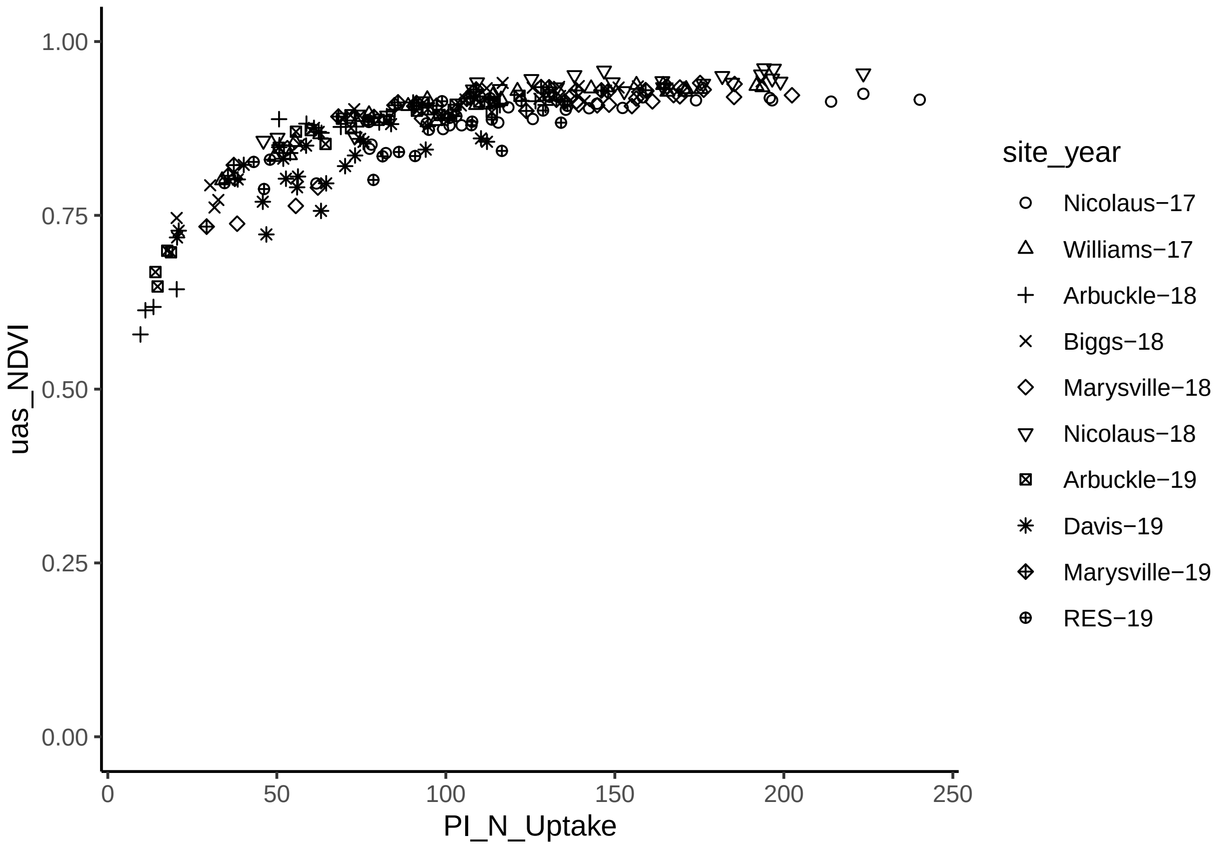

```
hist(drone_data$uas_NDVI)
```




```
ggplot(data = drone_data, aes(x = PI_N_Uptake , y = uas_NDRE )) +
  geom_point(mapping = aes(x = PI_N_Uptake , y = uas_NDRE , shape = site_year) , data = drone_data) +
  theme_classic() +
  scale_shape_manual(values = seq(4:20)) +
  coord_cartesian(ylim = c(0,1))
```




```
ggplot(data = drone_data, aes(x = PI_N_Uptake , y = uas_NDVI )) +
  geom_point(mapping = aes(x = PI_N_Uptake , y = uas_NDVI , shape = site_year) , data = drone_data) +
  theme_classic() +
  scale_shape_manual(values = seq(4:20)) +
  coord_cartesian(ylim = c(0,1))
```



Calculating UAS RI

```
#gets the max NDRE value for each site

max_drone_data <- drone_data %>%
  filter(N_level_kgha_f %in% c(225, 235)) %>%
  dplyr::select(site_year , uas_NDVI , uas_NDRE) %>%
  group_by(site_year) %>%
  summarise_all(.funs = mean) %>%
  ungroup()

nic17 <- subset(max_drone_data, site_year == "Nicolaus-17")
nic17maxuas_NDRE <- as.numeric(nic17$uas_NDRE)
nic17maxuas_NDRE
```

```
## [1] 0.7642401
```

```
nic17maxuas_NDVI <- as.numeric(nic17$uas_NDVI)
nic17maxuas_NDVI
```

```
## [1] 0.9186193
```

```
wil17 <- subset(max_drone_data, site_year == "Williams-17")
wil17maxuas_NDRE <- as.numeric(wil17$uas_NDRE)
wil17maxuas_NDRE
```

```
## [1] 0.7785445
```

```r
wil17maxuas_NDVI <- as.numeric(wil17$uas_NDVI)
wil17maxuas_NDVI
```

```
## [1] 0.9349728
```

```r
arb18 <- subset(max_drone_data, site_year == "Arbuckle-18")
arb18maxuas_NDRE <- as.numeric(arb18$uas_NDRE)
arb18maxuas_NDRE
```

```
## [1] 0.6151996
```

```r
arb18maxuas_NDVI <- as.numeric(arb18$uas_NDVI)
arb18maxuas_NDVI
```

```
## [1] 0.9113451
```

```r
biggs18 <- subset(max_drone_data, site_year == "Biggs-18")
biggs18maxuas_NDRE <- as.numeric(biggs18$uas_NDRE)
biggs18maxuas_NDRE
```

```
## [1] 0.6796539
```

```r
biggs18maxuas_NDVI <- as.numeric(biggs18$uas_NDVI)
biggs18maxuas_NDVI
```

```
## [1] 0.9342827
```

```r
mry18 <- subset(max_drone_data, site_year == "Marysville-18")
mry18maxuas_NDRE <- as.numeric(mry18$uas_NDRE)
mry18maxuas_NDRE
```

```
## [1] 0.6812887
```

```r
mry18maxuas_NDVI <- as.numeric(mry18$uas_NDVI)
mry18maxuas_NDVI
```

```
## [1] 0.9315267
```

```r
nic18 <- subset(max_drone_data, site_year == "Nicolaus-18")
nic18maxuas_NDRE <- as.numeric(nic18$uas_NDRE)
nic18maxuas_NDRE
```

```
## [1] 0.7430412
```

```r
nic18maxuas_NDVI <- as.numeric(nic18$uas_NDVI)
nic18maxuas_NDVI
```

```
## [1] 0.9558061
```

```r
arb19 <- subset(max_drone_data, site_year == "Arbuckle-19")
arb19maxuas_NDRE <- as.numeric(arb19$uas_NDRE)
arb19maxuas_NDRE
```

```
## [1] 0.6288361
```

```r
arb19maxuas_NDVI <- as.numeric(arb19$uas_NDVI)
arb19maxuas_NDVI
```

```
## [1] 0.9142775
```

```r
davis19 <- subset(max_drone_data, site_year == "Davis-19")
davis19maxuas_NDRE <- as.numeric(davis19$uas_NDRE)
davis19maxuas_NDRE
```

```
## [1] 0.5012478
```

```r
davis19maxuas_NDVI <- as.numeric(davis19$uas_NDVI)
davis19maxuas_NDVI
```

```
## [1] 0.8592071
```

```r
mry19 <- subset(max_drone_data, site_year == "Marysville-19")
mry19maxuas_NDRE <- as.numeric(mry19$uas_NDRE)
mry19maxuas_NDRE
```

```
## [1] 0.655337
```

```r
mry19maxuas_NDVI <- as.numeric(mry19$uas_NDVI)
mry19maxuas_NDVI
```

```
## [1] 0.9276236
```

```r
res19 <- subset(max_drone_data, site_year == "RES-19")
res19maxuas_NDRE <- as.numeric(res19$uas_NDRE)
res19maxuas_NDRE
```

```
## [1] 0.5945887
```

```r
res19maxuas_NDVI <- as.numeric(res19$uas_NDVI)
res19maxuas_NDVI
```

```
## [1] 0.8840389
```

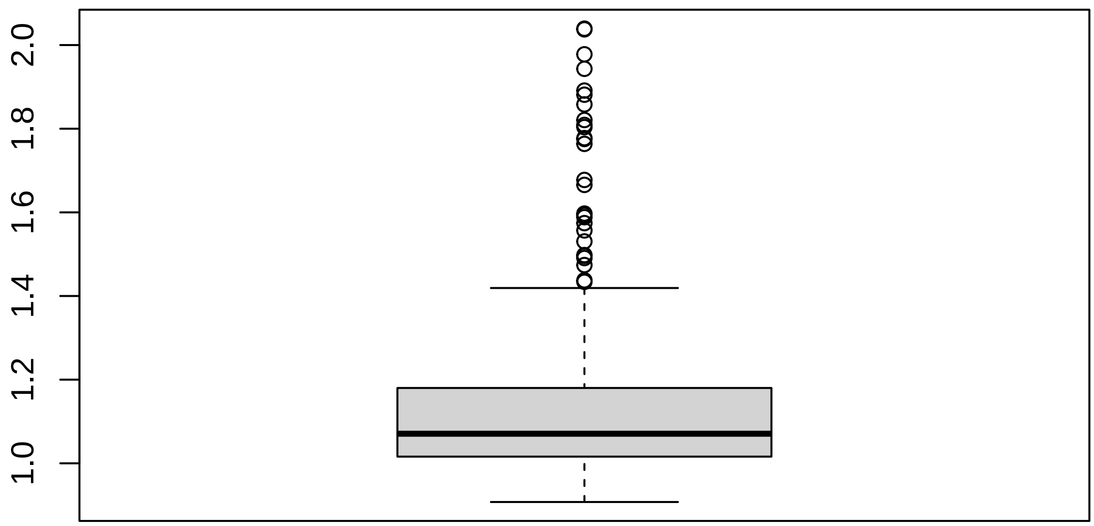
```r
drone_data <- drone_data %>%
  mutate(max_uas_NDRE = case_when(
                        site_year == "Nicolaus-17" ~ nic17maxuas_NDRE ,
                        site_year == "Williams-17" ~ wil17maxuas_NDRE ,
                        site_year == "Arbuckle-18" ~ arb18maxuas_NDRE ,
                        site_year == "Biggs-18" ~ biggs18maxuas_NDRE ,
                        site_year == "Marysville-18" ~ mry18maxuas_NDRE ,
                        site_year == "Nicolaus-18" ~ nic18maxuas_NDRE,
                        site_year == "Arbuckle-19" ~ arb19maxuas_NDRE ,
                        site_year == "Davis-19" ~ davis19maxuas_NDRE ,
                        site_year == "Marysville-19" ~ mry19maxuas_NDRE ,
                        site_year == "RES-19" ~ res19maxuas_NDRE) #assign the max NDRE value for each
  )

drone_data <- drone_data %>%
  mutate(uas_NDRE_Response_Index = case_when(
                        site_year == "Nicolaus-17" ~ nic17maxuas_NDRE / uas_NDRE,
                        site_year == "Williams-17" ~ wil17maxuas_NDRE / uas_NDRE,
                        site_year == "Arbuckle-18" ~ arb18maxuas_NDRE / uas_NDRE  ,
                        site_year == "Biggs-18" ~ biggs18maxuas_NDRE / uas_NDRE ,
                        site_year == "Marysville-18" ~ mry18maxuas_NDRE / uas_NDRE ,
                        site_year == "Nicolaus-18" ~ nic18maxuas_NDRE / uas_NDRE,
                        site_year == "Arbuckle-19" ~ arb19maxuas_NDRE / uas_NDRE,
                        site_year == "Davis-19" ~ davis19maxuas_NDRE / uas_NDRE,
                        site_year == "Marysville-19" ~ mry19maxuas_NDRE / uas_NDRE,
```

```r
                          site_year == "RES-19" ~ res19maxuas_NDRE / uas_NDRE
                        )) #calculates uas_NDRE response index

drone_data <- drone_data %>%
  mutate(max_uas_NDVI = case_when(
                          site_year == "Nicolaus-17" ~ nic17maxuas_NDVI ,
                          site_year == "Williams-17" ~ wil17maxuas_NDVI ,
                          site_year == "Arbuckle-18" ~ arb18maxuas_NDVI ,
                          site_year == "Biggs-18" ~ biggs18maxuas_NDVI ,
                          site_year == "Marysville-18" ~ mry18maxuas_NDVI ,
                          site_year == "Nicolaus-18" ~ nic18maxuas_NDVI,
                          site_year == "Arbuckle-19" ~ arb19maxuas_NDVI ,
                          site_year == "Davis-19" ~ davis19maxuas_NDVI ,
                          site_year == "Marysville-19" ~ mry19maxuas_NDVI ,
                          site_year == "RES-19" ~ res19maxuas_NDVI) #assign max ndvi value for each sit
  )

drone_data <- drone_data %>%
  mutate(uas_NDVI_Response_Index = case_when(
                          site_year == "Nicolaus-17" ~ nic17maxuas_NDVI / uas_NDVI,
                          site_year == "Williams-17" ~ wil17maxuas_NDVI / uas_NDVI,
                          site_year == "Arbuckle-18" ~ arb18maxuas_NDVI / uas_NDVI  ,
                          site_year == "Biggs-18" ~ biggs18maxuas_NDVI / uas_NDVI ,
                          site_year == "Marysville-18" ~ mry18maxuas_NDVI / uas_NDVI ,
                          site_year == "Nicolaus-18" ~ nic18maxuas_NDVI / uas_NDVI,
                          site_year == "Arbuckle-19" ~ arb19maxuas_NDVI / uas_NDVI,
                          site_year == "Davis-19" ~ davis19maxuas_NDVI / uas_NDVI,
                          site_year == "Marysville-19" ~ mry19maxuas_NDVI / uas_NDVI,
                          site_year == "RES-19" ~ res19maxuas_NDVI / uas_NDVI
                        )) #calculates uas_NDVI response index

str(drone_data , give.attr =  F)
```

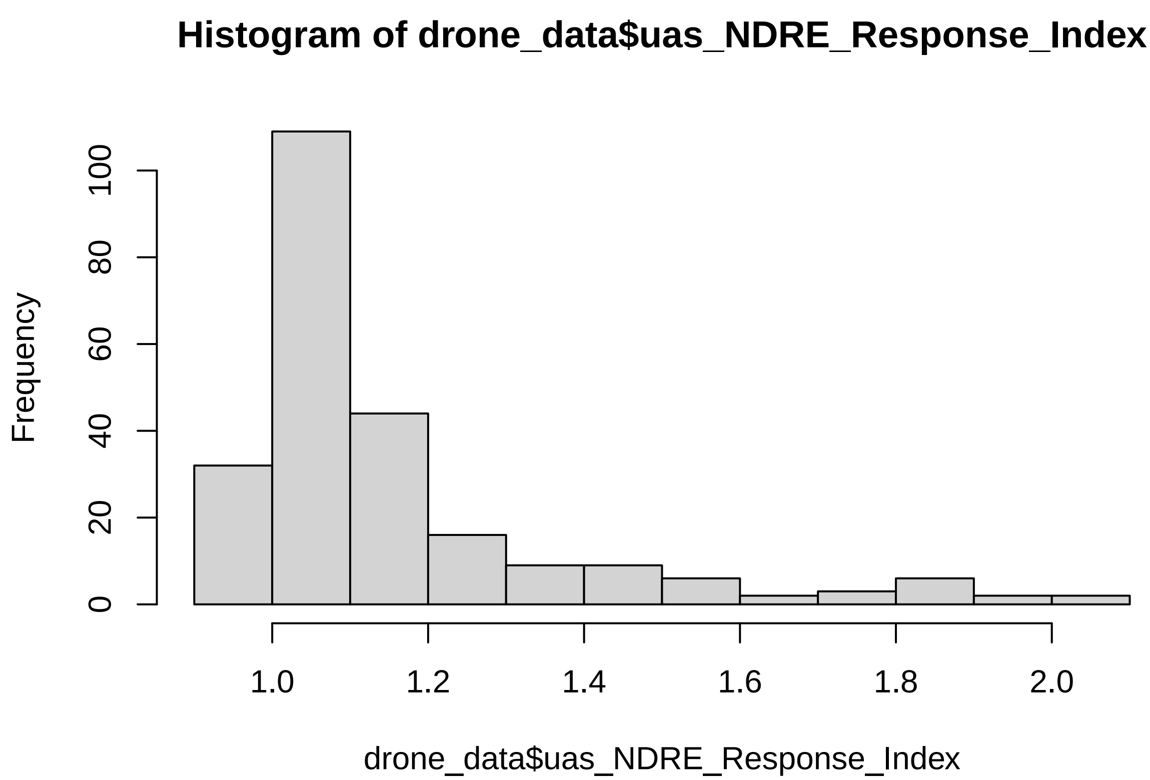
```
## tibble [240 x 29] (S3: tbl_df/tbl/data.frame)
##  $ site_year              : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year                   : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number        : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block                  : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot               : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ N_level                : Factor w/ 11 levels "0","45","75",..: 11 1 6 8 2 3 3 6 1 8 ...
##  $ N_level_kgha           : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f         : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ biomass_plus_bag_g     : num [1:240] 361 264 318 360 285 ...
##  $ ring_size              : num [1:240] 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
##  $ paper_bag_g            : num [1:240] 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 45.5 ...
##  $ num_of_paper_bags      : num [1:240] 1 1 1 1 1 1 1 1 1 1 ...
##  $ sample_weight_mg       : num [1:240] 3.17 3.42 3.09 3.07 3.2 ...
##  $ sample_N_ug            : num [1:240] 79.4 61.1 80.7 95.9 63.6 ...
##  $ bluemean               : num [1:240] NA NA NA NA NA NA NA NA NA NA ...
##  $ greenmean              : num [1:240] 0.0467 0.0581 0.0498 0.0488 0.0608 0.0589 0.0537 0.0488 0.05
##  $ redmean                : num [1:240] 0.023 0.0286 0.0243 0.0237 0.0292 0.0281 0.0263 0.0237 0.029
##  $ edgemean               : num [1:240] 0.0738 0.0867 0.0768 0.0764 0.0903 0.0877 0.0812 0.0754 0.08
##  $ nirmean                : num [1:240] 0.55 0.357 0.482 0.537 0.431 ...
##  $ biomass_dry_wt         : num [1:240] 316 219 273 315 239 ...
```

```
##  $ aboveground_biomass    : num [1:240] 6316 4376 5456 6296 4782 ...
##  $ n_content              : num [1:240] 25.1 17.8 26.1 31.2 19.9 ...
##  $ PI_N_Uptake            : num [1:240] 158 78 142 197 95 ...
##  $ uas_NDRE               : num [1:240] 0.763 0.609 0.725 0.751 0.653 ...
##  $ uas_NDVI               : num [1:240] 0.92 0.852 0.904 0.915 0.873 ...
##  $ max_uas_NDRE           : num [1:240] 0.764 0.764 0.764 0.764 0.764 ...
##  $ uas_NDRE_Response_Index: num [1:240] 1 1.25 1.05 1.02 1.17 ...
##  $ max_uas_NDVI           : num [1:240] 0.919 0.919 0.919 0.919 0.919 ...
##  $ uas_NDVI_Response_Index: num [1:240] 0.999 1.079 1.016 1.003 1.052 ...
```

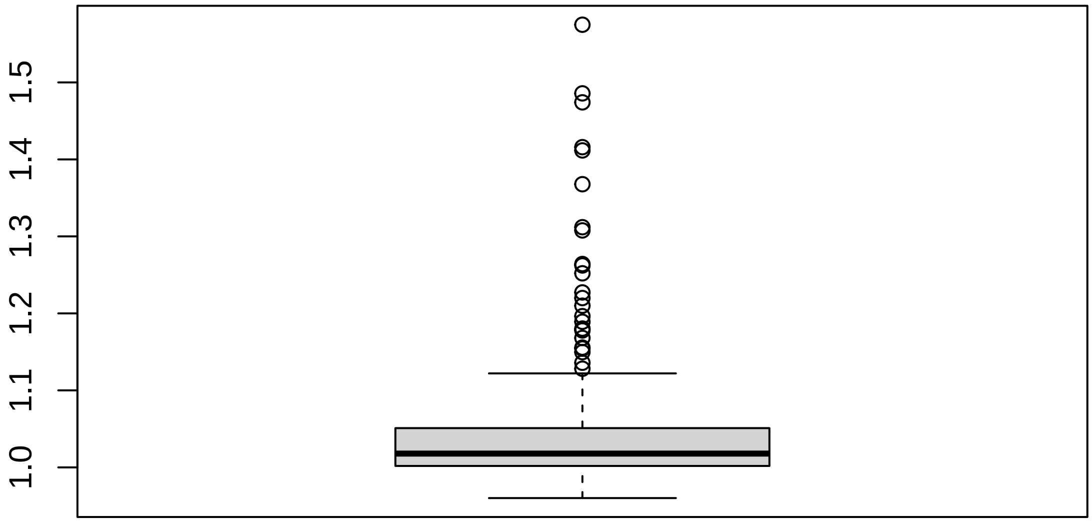
```
boxplot(drone_data$uas_NDRE_Response_Index)
```



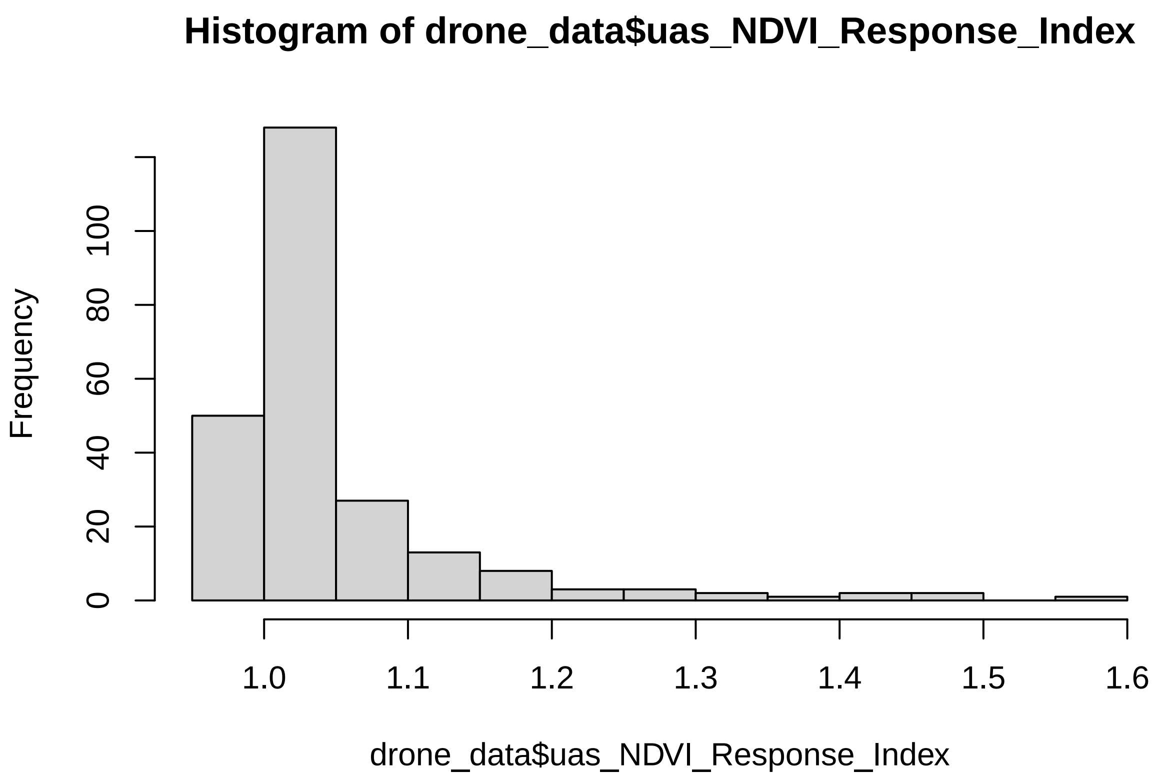

```
hist(drone_data$uas_NDRE_Response_Index)
```



```
boxplot(drone_data$uas_NDVI_Response_Index)
```




```
hist(drone_data$uas_NDVI_Response_Index)
```




```
drone_data <- dplyr::select(drone_data ,
                            site_year,
                            year,
                            exp_plot_number,
                            Block,
                            MainPlot,
                            N_level_kgha,
                            N_level_kgha_f,
                            PI_N_Uptake,
```

```r
                      uas_NDRE,
                      uas_NDVI,
                      uas_NDRE_Response_Index,
                      uas_NDVI_Response_Index
                      )#selects the relevant columns

sUAS_yield_data <- yield_data

sUAS_yield_data$site_year <- factor(sUAS_yield_data$site_year , levels = c("Nicolaus-17" , "Williams-17

str(drone_data , give.attr = F)
```

```
## tibble [240 x 12] (S3: tbl_df/tbl/data.frame)
##  $ site_year              : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year                   : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number        : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block                  : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot               : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ N_level_kgha           : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f         : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ PI_N_Uptake            : num [1:240] 158 78 142 197 95 ...
##  $ uas_NDRE               : num [1:240] 0.763 0.609 0.725 0.751 0.653 ...
##  $ uas_NDVI               : num [1:240] 0.92 0.852 0.904 0.915 0.873 ...
##  $ uas_NDRE_Response_Index: num [1:240] 1 1.25 1.05 1.02 1.17 ...
##  $ uas_NDVI_Response_Index: num [1:240] 0.999 1.079 1.016 1.003 1.052 ...
```

```r
str(sUAS_yield_data , give.attr = F)
```

```
## tibble [240 x 11] (S3: tbl_df/tbl/data.frame)
##  $ site_year      : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year           : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ Block          : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot       : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ SubPlot        : Factor w/ 3 levels "1","2","3": 2 3 1 1 1 2 1 1 2 3 ...
##  $ exp_plot_number: Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ N_level_kgha   : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ TopDress_kgha  : num [1:240] 0 0 0 0 0 0 0 0 0 0 ...
##  $ TopDress_kgha_f: Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ GrainYield_Mgha: num [1:240] 11.4 11 12 11.9 11.5 ...
```

```r
sUAS_data <- full_join( drone_data , sUAS_yield_data)
```

```
## Joining, by = c("site_year", "year", "exp_plot_number", "Block", "MainPlot",
## "N_level_kgha", "N_level_kgha_f")
```

```r
sUAS_data <- dplyr::select(sUAS_data ,
                      site_year,
                      year,
                      exp_plot_number,
                      Block,
                      MainPlot,
                      SubPlot,
                      N_level_kgha,
                      N_level_kgha_f,
                      TopDress_kgha,
```

```r
                      TopDress_kgha_f,
                      PI_N_Uptake,
                      uas_NDRE,
                      uas_NDVI,
                      GrainYield_Mgha,
                      uas_NDRE_Response_Index,
                      uas_NDVI_Response_Index
                      )#selects the relevant columns


str(sUAS_data , give.attr = F)
```

```
## tibble [240 x 16] (S3: tbl_df/tbl/data.frame)
##  $ site_year              : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year                   : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number        : Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block                  : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot               : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ SubPlot                : Factor w/ 3 levels "1","2","3": 2 3 1 1 1 2 1 1 2 3 ...
##  $ N_level_kgha           : num [1:240] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f         : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ TopDress_kgha          : num [1:240] 0 0 0 0 0 0 0 0 0 0 ...
##  $ TopDress_kgha_f        : Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ PI_N_Uptake            : num [1:240] 158 78 142 197 95 ...
##  $ uas_NDRE               : num [1:240] 0.763 0.609 0.725 0.751 0.653 ...
##  $ uas_NDVI               : num [1:240] 0.92 0.852 0.904 0.915 0.873 ...
##  $ GrainYield_Mgha        : num [1:240] 11.4 11 12 11.9 11.5 ...
##  $ uas_NDRE_Response_Index: num [1:240] 1 1.25 1.05 1.02 1.17 ...
##  $ uas_NDVI_Response_Index: num [1:240] 0.999 1.079 1.016 1.003 1.052 ...
```

Combining the data

```r
gs_data <- gs_data %>%
  mutate(gs_NDVI_SI = 1 / gs_NDVI_Response_Index)

sUAS_data <- sUAS_data %>%
  mutate(uas_NDVI_SI = 1 / uas_NDVI_Response_Index)

sUAS_data <- sUAS_data %>%
  mutate(uas_NDRE_SI = 1 / uas_NDRE_Response_Index)

gs_data <- gs_data %>%
  dplyr::select(site_year ,
                year,
                exp_plot_number,
                Block,
                MainPlot,
                SubPlot,
                N_level_kgha,
                N_level_kgha_f,
                TopDress_kgha,
                TopDress_kgha_f,
                PI_N_Uptake,
```

```
                NDVI,
                GrainYield_Mgha,
                gs_NDVI_Response_Index,
                gs_NDVI_SI
         )

sUAS_data <- sUAS_data %>%
  dplyr::select(site_year ,
                year,
                exp_plot_number,
                Block,
                MainPlot,
                SubPlot,
                N_level_kgha,
                N_level_kgha_f,
                TopDress_kgha,
                TopDress_kgha_f,
                uas_NDRE,
                uas_NDVI,
                uas_NDVI_Response_Index,
                uas_NDVI_SI,
                uas_NDRE_Response_Index,
                uas_NDRE_SI
         )

paper3_data <- full_join(gs_data , sUAS_data)
```

```
## Joining, by = c("site_year", "year", "exp_plot_number", "Block", "MainPlot",
## "SubPlot", "N_level_kgha", "N_level_kgha_f", "TopDress_kgha",
## "TopDress_kgha_f")
```

```
paper3_gsdata <- paper3_data %>%
  dplyr::select(site_year ,
                year ,
                exp_plot_number ,
                Block ,
                MainPlot ,
                SubPlot ,
                N_level_kgha ,
                N_level_kgha_f ,
                TopDress_kgha ,
                TopDress_kgha_f ,
                NDVI,
                gs_NDVI_Response_Index,
                gs_NDVI_SI ,
                GrainYield_Mgha,
                PI_N_Uptake) %>%
  mutate(Platform = "GreenSeeker NDVI" ) %>%
  rename(Index = NDVI ,
         SI = gs_NDVI_SI,
         RI = gs_NDVI_Response_Index)

paper3_uas_ndvi_data <- paper3_data %>%
  dplyr::select(site_year ,
```

```
                year ,
                exp_plot_number ,
                Block ,
                MainPlot ,
                SubPlot ,
                N_level_kgha ,
                N_level_kgha_f ,
                TopDress_kgha ,
                TopDress_kgha_f ,
                uas_NDVI,
                uas_NDVI_Response_Index,
                uas_NDVI_SI ,
                GrainYield_Mgha,
                PI_N_Uptake) %>%
  mutate(Platform = "sUAS NDVI" ) %>%
  rename(Index = uas_NDVI,
         SI = uas_NDVI_SI,
         RI = uas_NDVI_Response_Index)

paper3_uas_ndre_data <- paper3_data %>%
  dplyr::select(site_year ,
                year ,
                exp_plot_number ,
                Block ,
                MainPlot ,
                SubPlot ,
                N_level_kgha ,
                N_level_kgha_f ,
                TopDress_kgha ,
                TopDress_kgha_f ,
                uas_NDRE ,
                uas_NDRE_Response_Index ,
                uas_NDRE_SI ,
                GrainYield_Mgha,
                PI_N_Uptake) %>%
  mutate(Platform = "sUAS NDRE" ) %>%
  rename(Index = uas_NDRE ,
         SI = uas_NDRE_SI,
         RI = uas_NDRE_Response_Index)

paper3_data <- rbind(paper3_gsdata ,
                     paper3_uas_ndvi_data ,
                     paper3_uas_ndre_data)

paper3_data <- paper3_data %>%
  dplyr::select(site_year ,
                year ,
                Platform,
                exp_plot_number ,
                Block ,
                MainPlot ,
                SubPlot ,
                N_level_kgha ,
                N_level_kgha_f ,
```

```
                TopDress_kgha ,
                TopDress_kgha_f ,
                Index,
                RI,
                SI ,
                GrainYield_Mgha,
                PI_N_Uptake)

paper3_data$Platform <- as.factor(paper3_data$Platform)

str(paper3_data , give.attr = F)
```

```
## rowwise_df [720 x 16] (S3: rowwise_df/tbl_df/tbl/data.frame)
##  $ site_year      : Factor w/ 10 levels "Nicolaus-17",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ year           : Factor w/ 3 levels "2017","2018",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ Platform       : Factor w/ 3 levels "GreenSeeker NDVI",..: 1 1 1 1 1 1 1 1 1 1 ...
##  $ exp_plot_number: Factor w/ 27 levels "101","102","103",..: 1 2 3 4 6 7 9 10 11 12 ...
##  $ Block          : Factor w/ 4 levels "1","2","3","4": 1 1 1 1 1 1 2 2 2 2 ...
##  $ MainPlot       : Factor w/ 7 levels "1","2","3","4",..: 1 2 3 4 6 7 2 3 4 5 ...
##  $ SubPlot        : Factor w/ 3 levels "1","2","3": 2 3 1 1 1 2 1 1 2 3 ...
##  $ N_level_kgha   : num [1:720] 225 0 125 175 45 75 75 125 0 175 ...
##  $ N_level_kgha_f : Factor w/ 11 levels "0","45","75",..: 10 1 5 8 2 3 3 5 1 8 ...
##  $ TopDress_kgha  : num [1:720] 0 0 0 0 0 0 0 0 0 0 ...
##  $ TopDress_kgha_f: Factor w/ 1 level "0": 1 1 1 1 1 1 1 1 1 1 ...
##  $ Index          : num [1:720] 0.777 0.493 0.683 0.787 0.683 ...
##  $ RI             : num [1:720] 1.012 1.593 1.15 0.999 1.15 ...
##  $ SI             : num [1:720] 0.988 0.628 0.87 1.001 0.87 ...
##  $ GrainYield_Mgha: num [1:720] 11.4 11 12 11.9 11.5 ...
##  $ PI_N_Uptake    : num [1:720] 158 78 142 197 95 ...
```

```
paper3_data <- tibble::rowid_to_column(paper3_data, "ID") #adds a columns with row number.
```

Calculating Relative Yield

```
nic17 <- subset(paper3_data, site_year == "Nicolaus-17")
nic17 <- apply(nic17,2,max)
nic17max_yield <- as.numeric(nic17[16])

wil17 <- subset(paper3_data, site_year == "Williams-17")
wil17 <- apply(wil17,2,max)
wil17max_yield <- as.numeric(wil17[16])

arb18 <- subset(paper3_data, site_year == "Arbuckle-18")
arb18 <- apply(arb18,2,max)
arb18max_yield <- as.numeric(arb18[16])

nic18 <- subset(paper3_data, site_year == "Nicolaus-18")
nic18 <- apply(nic18,2,max)
nic18max_yield <- as.numeric(nic18[16])

mry18 <- subset(paper3_data, site_year == "Marysville-18")
mry18 <- apply(mry18,2,max)
mry18max_yield <- as.numeric(mry18[16])
```

```r
biggs18 <- subset(paper3_data, site_year == "Biggs-18")
biggs18 <- apply(biggs18,2,max)
biggs18max_yield <- as.numeric(biggs18[16])

arb19 <- subset(paper3_data, site_year == "Arbuckle-19")
arb19 <- apply(arb19,2,max)
arb19max_yield <- as.numeric(arb19[16])

dav19 <- subset(paper3_data, site_year == "Davis-19")
dav19 <- apply(dav19,2,max)
dav19max_yield <- as.numeric(dav19[16])

mry19 <- subset(paper3_data, site_year == "Marysville-19")
mry19 <- apply(mry19,2,max)
mry19max_yield <- as.numeric(mry19[16])

res19 <- subset(paper3_data, site_year == "RES-19")
res19 <- apply(res19,2,max)
res19max_yield <- as.numeric(res19[16])


paper3_data <- paper3_data %>%
  mutate(relative_grain_yield = case_when(
                          site_year == "Nicolaus-17" ~ GrainYield_Mgha / nic17max_yield ,
                          site_year == "Williams-17" ~ GrainYield_Mgha / wil17max_yield ,
                          site_year == "Arbuckle-18" ~ GrainYield_Mgha / arb18max_yield ,
                          site_year == "Nicolaus-18" ~ GrainYield_Mgha / nic18max_yield ,
                          site_year == "Marysville-18" ~ GrainYield_Mgha / mry18max_yield ,
                          site_year == "Biggs-18" ~ GrainYield_Mgha / biggs18max_yield,
                          site_year == "Arbuckle-19" ~ GrainYield_Mgha / arb19max_yield ,
                          site_year == "Davis-19" ~ GrainYield_Mgha / dav19max_yield ,
                          site_year == "Marysville-19" ~ GrainYield_Mgha / mry19max_yield ,
                          site_year == "RES-19" ~ GrainYield_Mgha / res19max_yield))
```

Outlier Removal

```r
filter1 <- paper3_data %>%
  filter(site_year == "Biggs-18" & exp_plot_number == 101)

paper3_data <- paper3_data %>%
  filter(!ID %in% filter1$ID) #removes Biggs-18 plot 101 plot bc tractor ran through it

paper3_data$Platform = factor(paper3_data$Platform, levels=c( "GreenSeeker NDVI" ,  "sUAS NDRE" , "sUAS

paper3_data$RI[paper3_data$RI < 1] <- 1 #converts values less than 1, to 1.
paper3_data$SI[paper3_data$SI > 1] <- 1 #converts values less than 1, to 1.

hist_data <- paper3_data %>%
  dplyr::select(Platform , RI) %>%
  group_by(Platform) %>%
  summarise(mean = mean(RI) , sd = sd(RI) , median = median(RI))

hist_data_gs <- hist_data %>%
```

```r
  filter(Platform == "GreenSeeker NDVI")

upper_limit <- hist_data_gs[2] + (5*hist_data_gs[3]) #upper limit for outlier removal. Observations tha

print(upper_limit)
```

```
##       mean
## 1 3.690994
```

```r
#need to remove Arbuckle-18 plot 203 and Arbuckle-19 plot 104

filter1 <- paper3_data %>%
  filter(site_year == "Arbuckle-18" & exp_plot_number == 203)

filter2 <- paper3_data %>%
  filter(site_year == "Arbuckle-19" & exp_plot_number == 104)

filter <- rbind(filter1 , filter2)

filter$ID
```

```
## [1]  57 297 537 148 388 628
```

```r
paper3_data <- paper3_data %>%
  filter(!ID %in% filter$ID)

paper3_gsdata <- paper3_data %>%
  filter(Platform == "GreenSeeker NDVI")

paper3_uas_ndvi_data <- paper3_data %>%
  filter(Platform == "sUAS NDVI")

paper3_uas_ndre_data <- paper3_data %>%
  filter(Platform == "sUAS NDRE")
```

FIGURE 2

Data

```r
suppl_data <- paper3_data

suppl_data1 <- suppl_data %>%
  dplyr::select(site_year, N_level_kgha , TopDress_kgha_f , GrainYield_Mgha , PI_N_Uptake) %>%
  group_by(site_year , N_level_kgha ,TopDress_kgha_f ) %>%
  summarise_all(mean) %>%
  mutate(PI_N_Uptake_r = round(PI_N_Uptake , digits = 0),
         GrainYield_Mgha_r = round(GrainYield_Mgha , digits = 1)) %>%
  ungroup()

factor_list <- list( site = suppl_data1$site_year)

tapply(suppl_data1$GrainYield_Mgha_r, factor_list , max)
```

```
## site
##   Nicolaus-17   Williams-17   Arbuckle-18      Biggs-18 Marysville-18
```

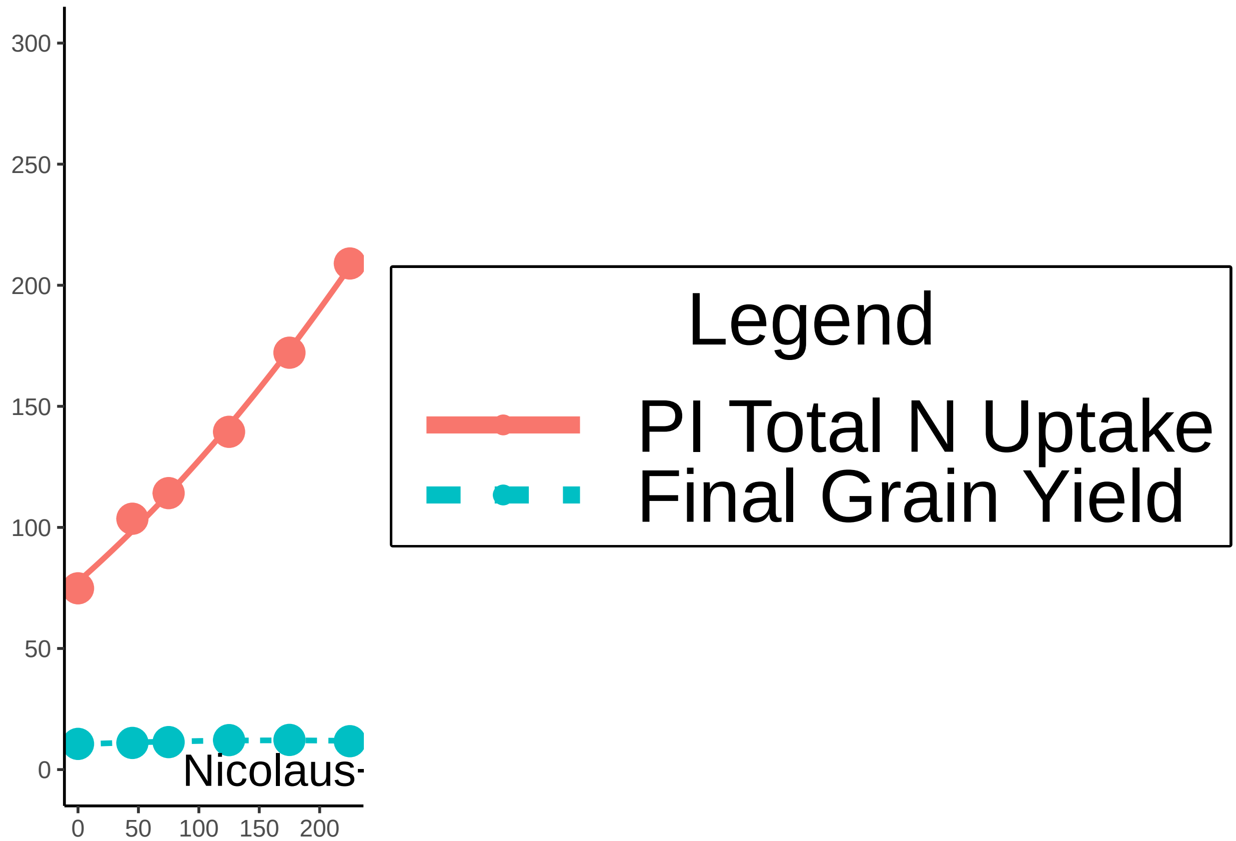
```
##          12.2          11.1          12.7          12.3          11.3
##   Nicolaus-18   Arbuckle-19      Davis-19 Marysville-19        RES-19
##          13.3          11.5          10.7          10.7           9.1
```

```
tapply(suppl_data1$GrainYield_Mgha_r, factor_list , min)
```

```
## site
##   Nicolaus-17   Williams-17   Arbuckle-18      Biggs-18 Marysville-18
##          10.6           6.6           3.2           7.3           8.7
##   Nicolaus-18   Arbuckle-19      Davis-19 Marysville-19        RES-19
##           9.2           4.2           7.6           6.9           6.0
```

Legend

```
suppl_data1_nic17 <- suppl_data1 %>%
  filter(site_year == "Nicolaus-17")

suppl_data1_nic17_yield <- suppl_data1_nic17 %>%
  dplyr::select(-c(PI_N_Uptake)) %>%
  mutate(Legend = as.factor("Final Grain Yield")) %>%
  rename("Unit" = GrainYield_Mgha)

suppl_data1_nic17_nup <- suppl_data1_nic17 %>%
  dplyr::select(-c(GrainYield_Mgha)) %>%
  mutate(Legend = as.factor("PI Total N Uptake")) %>%
  rename("Unit" = PI_N_Uptake)

suppl_data1_nic17 <- rbind(suppl_data1_nic17_nup , suppl_data1_nic17_yield)

nic17_plot_legend <- ggplot(data = suppl_data1_nic17 , aes( x = N_level_kgha , y = Unit , color = Legend
  geom_point(data = suppl_data1_nic17 , aes ( x = N_level_kgha , y = Unit , color = Legend) , size = 5)
  scale_y_continuous(breaks = seq(0 , 300 , by = 50)) +
  coord_cartesian(ylim = c(0 , 300)) +
  theme_classic() +
  theme(legend.text = element_text(size = 28 ),
        legend.title = element_text(size = 28 ),
        legend.box.background = element_rect(size = 1)) +
  annotate("text" , x = 190 , y = 0 , label = "Nicolaus-17" , size = 6) +
  labs( x = NULL , y = NULL) +
  geom_smooth(method = "lm", formula = y ~ poly(x, 2), se = FALSE) +
  guides(size = "none" , color = guide_legend(keywidth = 5 , keyheight = 1.5 , unit = "cm" , override.a

nic17_plot_legend
```

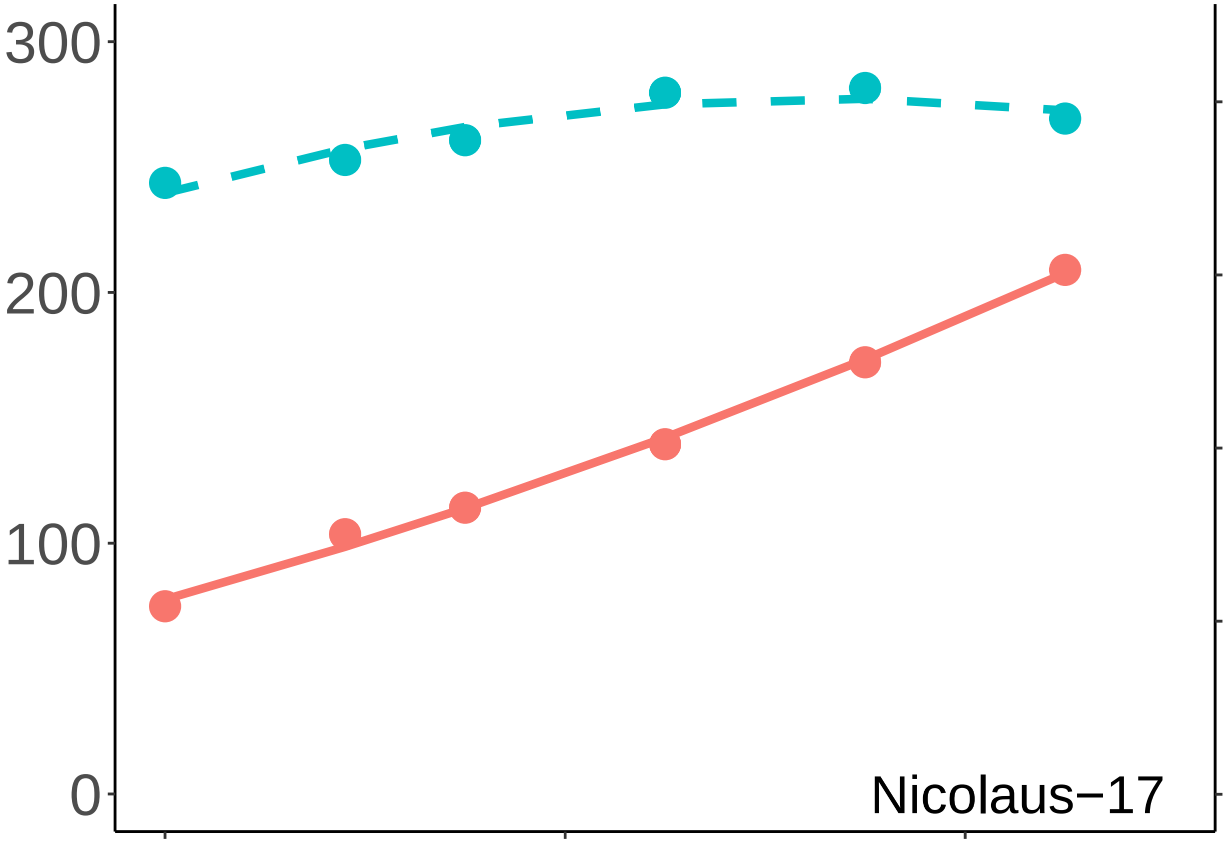



```
legend <- get_legend(nic17_plot_legend)
```

Nicolaus-17

```
suppl_data1_nic17 <- suppl_data1 %>%
  filter(site_year == "Nicolaus-17")

nic17_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_ni

nic17_fitted <- fitted(nic17_nuptake_lm)
nic17_df <- data.frame(suppl_data1_nic17$N_level_kgha , nic17_fitted) #creates dataframe

nic17_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

nic17_fitted_2 <- (fitted(nic17_yield_lm)*23)
nic17_df_2 <- data.frame(suppl_data1_nic17$N_level_kgha , nic17_fitted_2) #creates dataframe

nic17_plot <- ggplot(data = suppl_data1_nic17 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_nic17 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_nic17 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00B
  geom_line(data = nic17_df , aes( x = suppl_data1_nic17.N_level_kgha , y = nic17_fitted) , color = "#F8
  geom_line(data = nic17_df_2 , aes( x = suppl_data1_nic17.N_level_kgha , y = nic17_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y = element_text(size = 22),
```

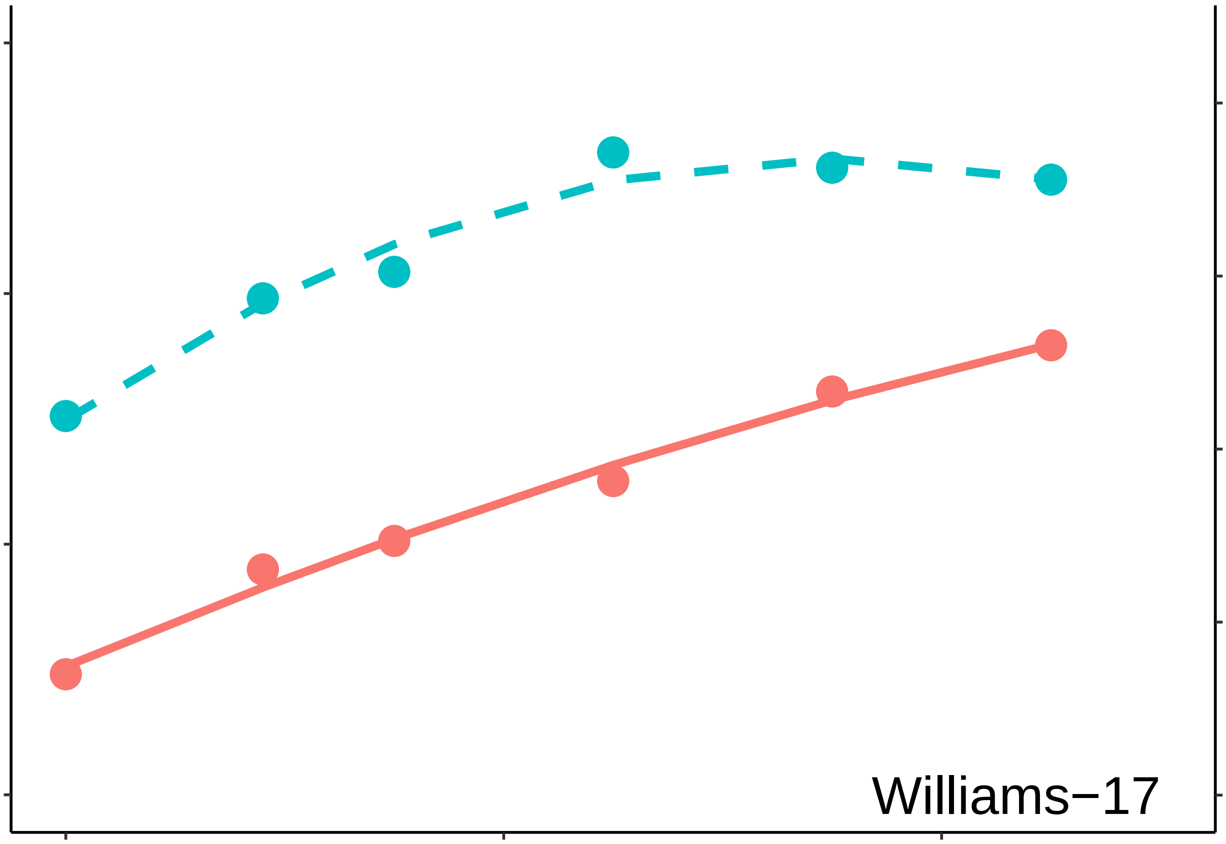
```
      axis.text.y.right = element_blank(),
      axis.text.x = element_blank()) +
  annotate("text" , x = 250 , y = 0 , label = "Nicolaus-17" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


nic17_plot
```



Williams-17

```
suppl_data1_wil17 <- suppl_data1 %>%
  filter(site_year == "Williams-17")

wil17_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_wi

wil17_fitted <- fitted(wil17_nuptake_lm)
wil17_df <- data.frame(suppl_data1_wil17$N_level_kgha , wil17_fitted) #creates dataframe

wil17_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

wil17_fitted_2 <- (fitted(wil17_yield_lm)*23)
wil17_df_2 <- data.frame(suppl_data1_wil17$N_level_kgha , wil17_fitted_2) #creates dataframe

wil17_plot <- ggplot(data = suppl_data1_wil17 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_wil17 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_wil17 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00E
```

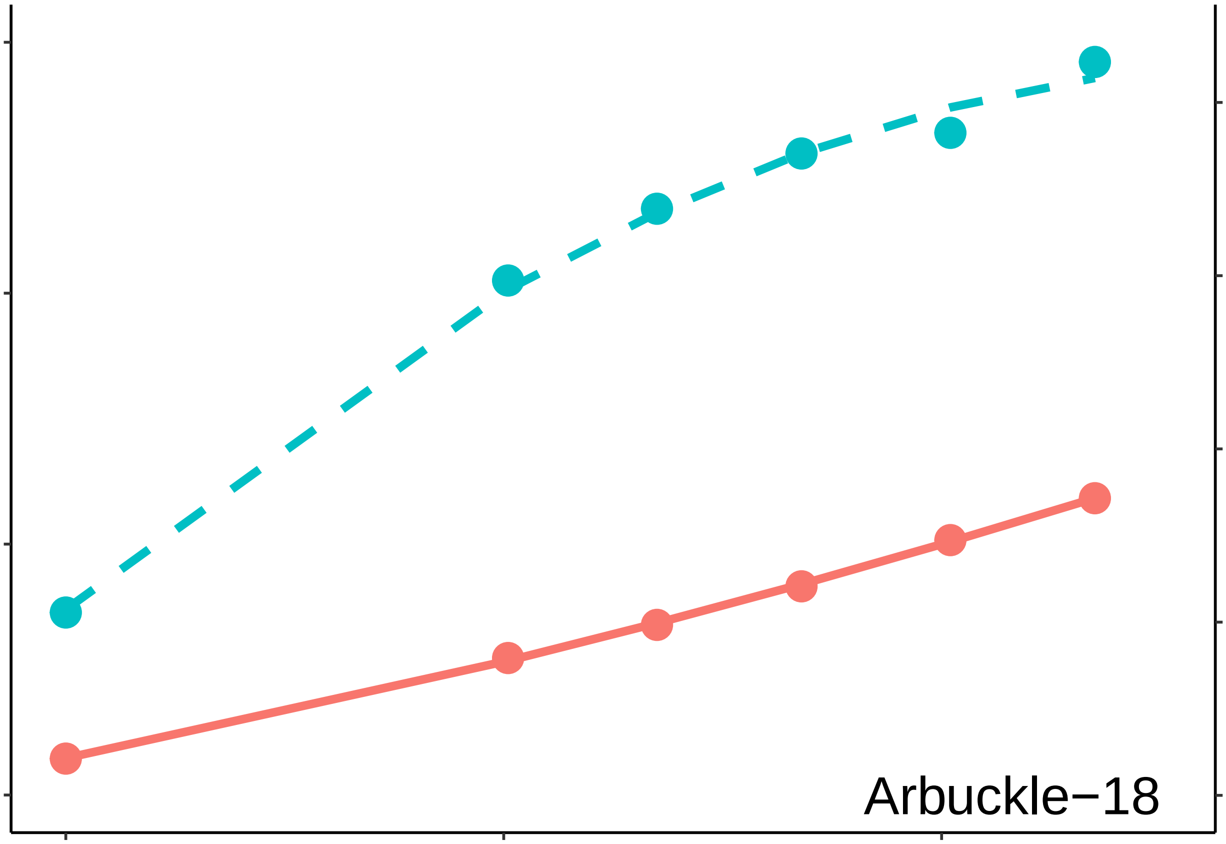
```
  geom_line(data = wil17_df , aes( x = suppl_data1_wil17.N_level_kgha , y = wil17_fitted) , color = "#F8
  geom_line(data = wil17_df_2 , aes( x = suppl_data1_wil17.N_level_kgha , y = wil17_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y = element_blank(),
        axis.text.x = element_blank()) +
  annotate("text" , x = 250 , y = 0 , label = "Williams-17" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


wil17_plot
```



Arbuckle-18

```
suppl_data1_arb18 <- suppl_data1 %>%
  filter(site_year == "Arbuckle-18")

arb18_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_ar

arb18_fitted <- fitted(arb18_nuptake_lm)
arb18_df <- data.frame(suppl_data1_arb18$N_level_kgha , arb18_fitted) #creates dataframe

arb18_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_
```

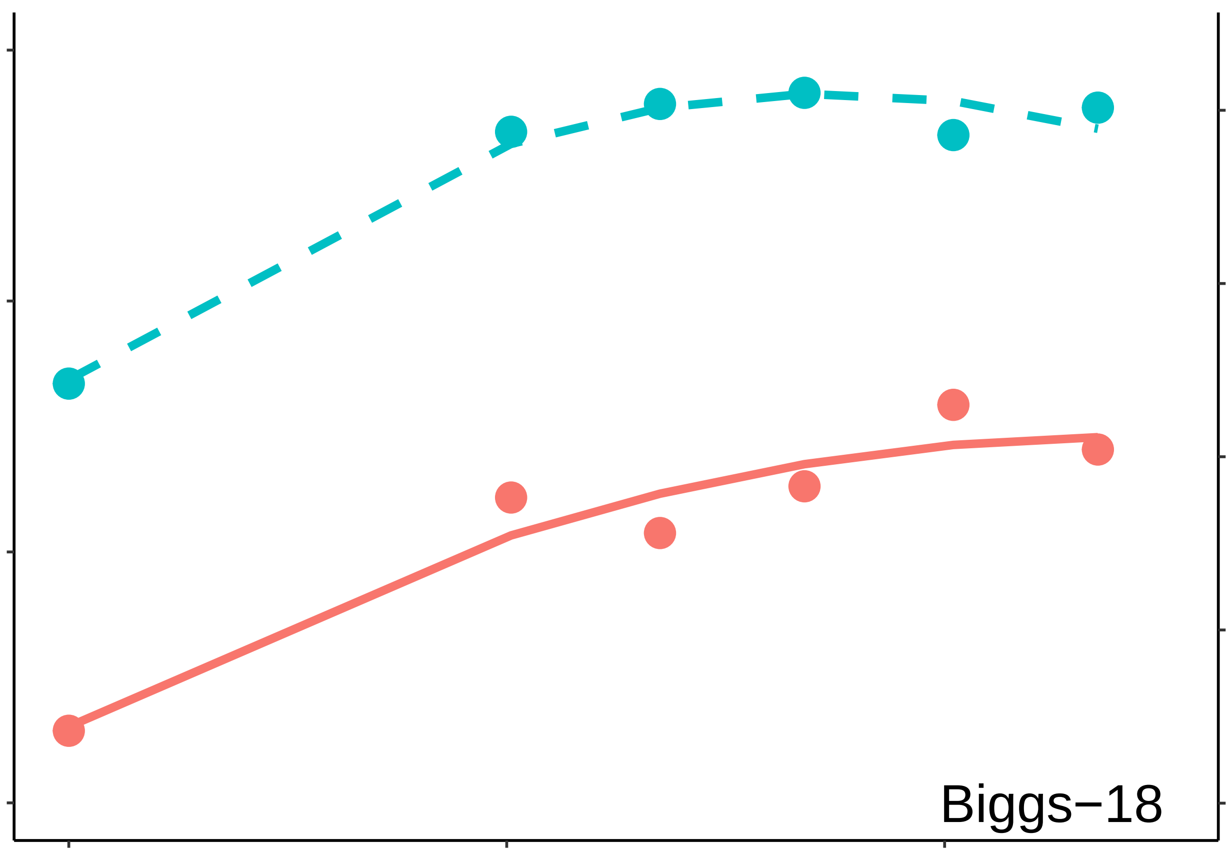
```
arb18_fitted_2 <- (fitted(arb18_yield_lm)*23)
arb18_df_2 <- data.frame(suppl_data1_arb18$N_level_kgha , arb18_fitted_2) #creates dataframe

arb18_plot <- ggplot(data = suppl_data1_arb18 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_arb18 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_arb18 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00B
  geom_line(data = arb18_df , aes( x = suppl_data1_arb18.N_level_kgha , y = arb18_fitted) , color = "#F8
  geom_line(data = arb18_df_2 , aes( x = suppl_data1_arb18.N_level_kgha , y = arb18_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y = element_blank(),
        axis.text.x = element_blank()) +
  annotate("text" , x = 250 , y = 0 , label = "Arbuckle-18" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


arb18_plot
```



Biggs-18

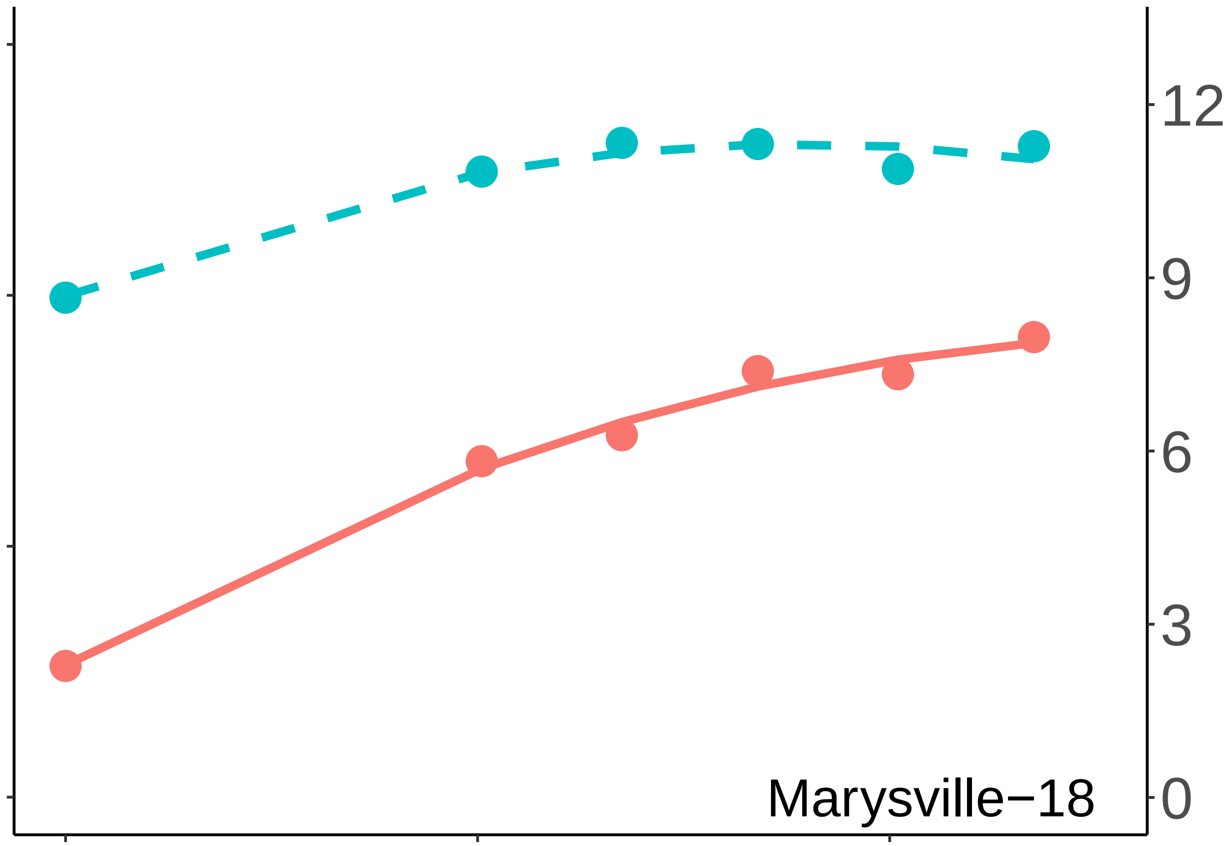
```
suppl_data1_biggs18 <- suppl_data1 %>%
  filter(site_year == "Biggs-18" )

biggs18_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_
```

```r
biggs18_fitted <- fitted(biggs18_nuptake_lm)
biggs18_df <- data.frame(suppl_data1_biggs18$N_level_kgha , biggs18_fitted) #creates dataframe

biggs18_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data

biggs18_fitted_2 <- (fitted(biggs18_yield_lm)*23)
biggs18_df_2 <- data.frame(suppl_data1_biggs18$N_level_kgha , biggs18_fitted_2) #creates dataframe

biggs18_plot <- ggplot(data = suppl_data1_biggs18 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_biggs18 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D"
  geom_point(data = suppl_data1_biggs18 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#
  geom_line(data = biggs18_df , aes( x = suppl_data1_biggs18.N_level_kgha , y = biggs18_fitted) , color
  geom_line(data = biggs18_df_2 , aes( x = suppl_data1_biggs18.N_level_kgha , y = biggs18_fitted_2) , c
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 1
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y = element_blank(),
        axis.text.x = element_blank()) +
  annotate("text" , x = 250 , y = 0 , label = "Biggs-18" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


biggs18_plot
```



Marysville-18

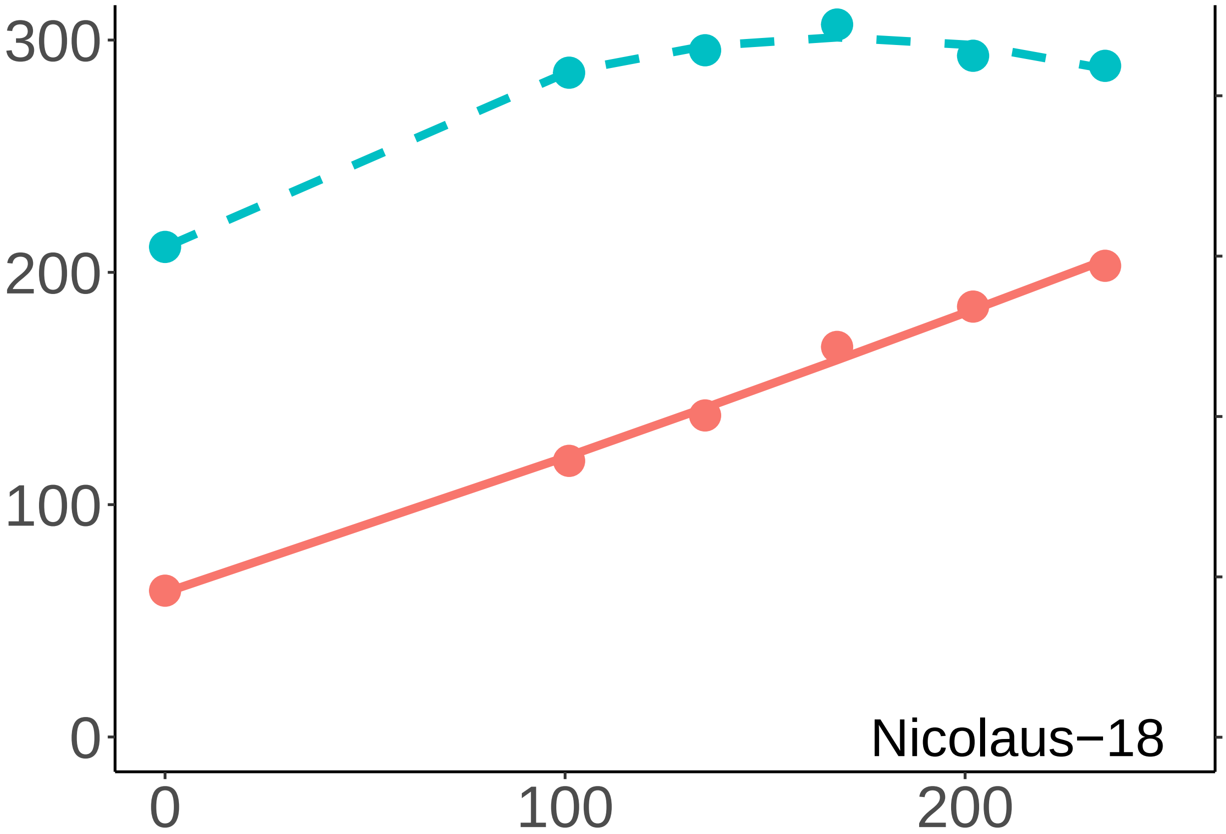
```
suppl_data1_mry18 <- suppl_data1 %>%
  filter(site_year == "Marysville-18" )

mry18_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_mr

mry18_fitted <- fitted(mry18_nuptake_lm)
mry18_df <- data.frame(suppl_data1_mry18$N_level_kgha , mry18_fitted) #creates dataframe

mry18_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

mry18_fitted_2 <- (fitted(mry18_yield_lm)*23)
mry18_df_2 <- data.frame(suppl_data1_mry18$N_level_kgha , mry18_fitted_2) #creates dataframe

mry18_plot <- ggplot(data = suppl_data1_mry18 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_mry18 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_mry18 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00B
  geom_line(data = mry18_df , aes( x = suppl_data1_mry18.N_level_kgha , y = mry18_fitted) , color = "#F8
  geom_line(data = mry18_df_2 , aes( x = suppl_data1_mry18.N_level_kgha , y = mry18_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y.right = element_text(size = 22),
        axis.text.y.left = element_blank(),
        axis.text.x = element_blank()) +
  annotate("text" , x = 250 , y = 0 , label = "Marysville-18" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


mry18_plot
```



Nicolaus-18

```
suppl_data1_nic18 <- suppl_data1 %>%
  filter(site_year == "Nicolaus-18" )

nic18_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_ni

nic18_fitted <- fitted(nic18_nuptake_lm)
nic18_df <- data.frame(suppl_data1_nic18$N_level_kgha , nic18_fitted) #creates dataframe

nic18_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

nic18_fitted_2 <- (fitted(nic18_yield_lm)*23)
nic18_df_2 <- data.frame(suppl_data1_nic18$N_level_kgha , nic18_fitted_2) #creates dataframe

nic18_plot <- ggplot(data = suppl_data1_nic18 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_nic18 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_nic18 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00B
  geom_line(data = nic18_df , aes( x = suppl_data1_nic18.N_level_kgha , y = nic18_fitted) , color = "#F8
  geom_line(data = nic18_df_2 , aes( x = suppl_data1_nic18.N_level_kgha , y = nic18_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y.right = element_blank(),
        axis.text.x = element_text(size = 22),
```

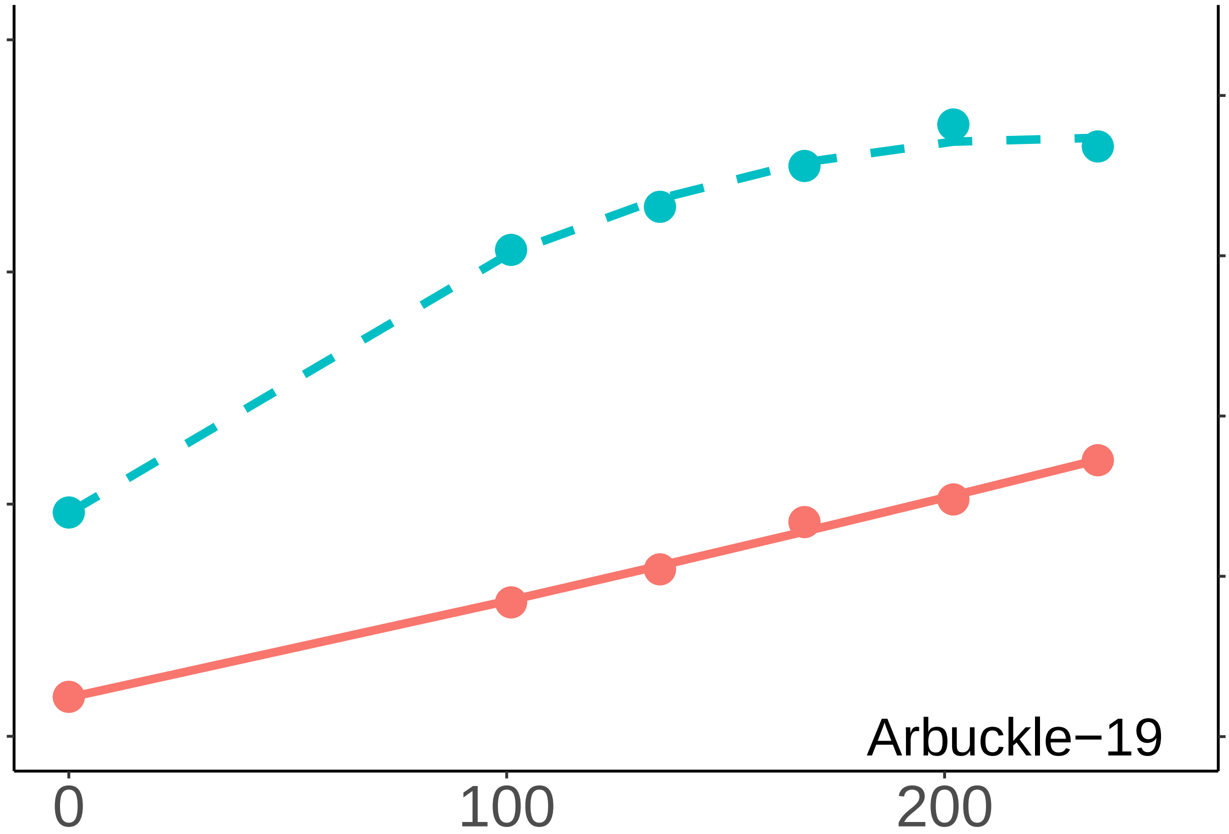
```
      axis.text.y.left = element_text(size = 22)) +
  annotate("text" , x = 250 , y = 0 , label = "Nicolaus-18" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


nic18_plot
```



Arbuckle-19

```
suppl_data1_arb19 <- suppl_data1 %>%
  filter(site_year == "Arbuckle-19" )

arb19_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_a

arb19_fitted <- fitted(arb19_nuptake_lm)
arb19_df <- data.frame(suppl_data1_arb19$N_level_kgha , arb19_fitted) #creates dataframe

arb19_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1

arb19_fitted_2 <- (fitted(arb19_yield_lm)*23)
arb19_df_2 <- data.frame(suppl_data1_arb19$N_level_kgha , arb19_fitted_2) #creates dataframe

arb19_plot <- ggplot(data = suppl_data1_arb19 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_arb19 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_arb19 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00
  geom_line(data = arb19_df , aes( x = suppl_data1_arb19.N_level_kgha , y = arb19_fitted) , color = "#F
```

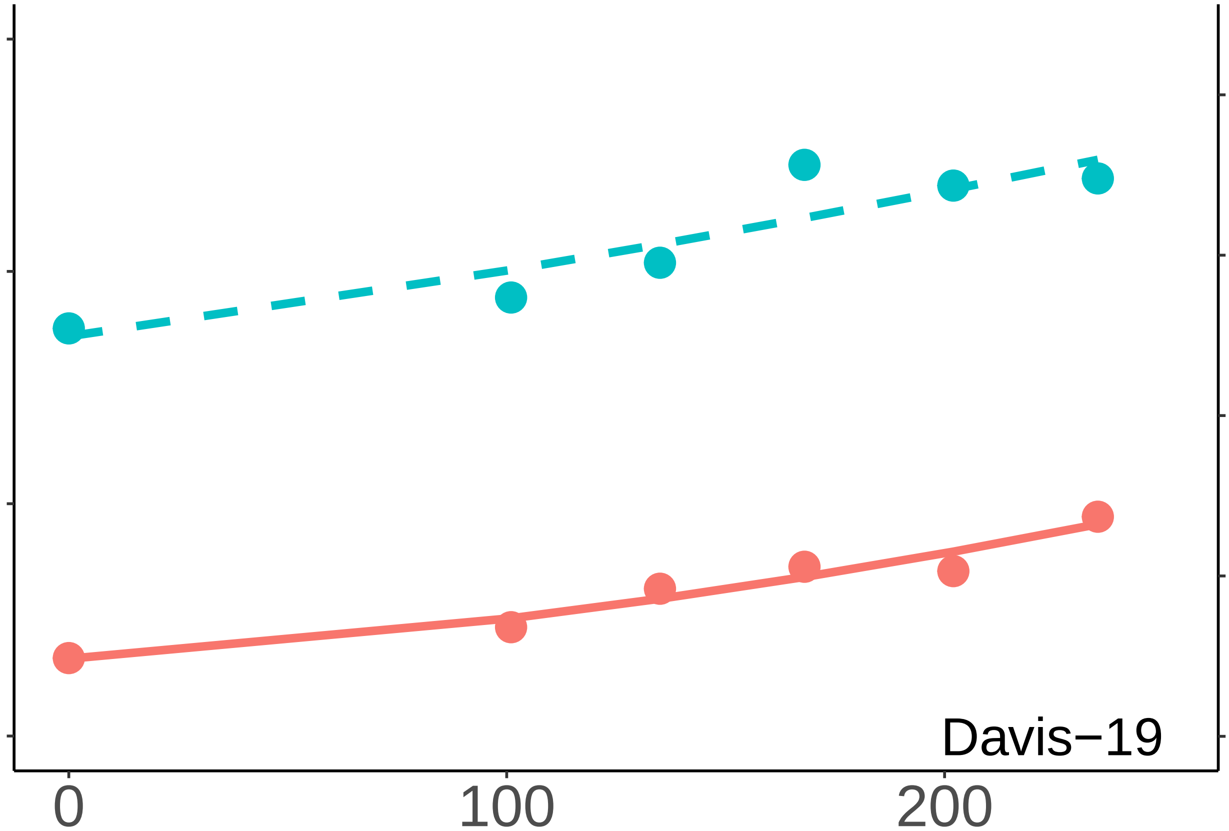
```
  geom_line(data = arb19_df_2 , aes( x = suppl_data1_arb19.N_level_kgha , y = arb19_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 1
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y = element_blank(),
        axis.text.x = element_text(size = 22)) +
  annotate("text" , x = 250 , y = 0 , label = "Arbuckle-19" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


arb19_plot
```



Davis-19

```
suppl_data1_davis19 <- suppl_data1 %>%
  filter(site_year == "Davis-19" )

davis19_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

davis19_fitted <- fitted(davis19_nuptake_lm)
davis19_df <- data.frame(suppl_data1_davis19$N_level_kgha , davis19_fitted) #creates dataframe

davis19_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data

davis19_fitted_2 <- (fitted(davis19_yield_lm)*23)
```

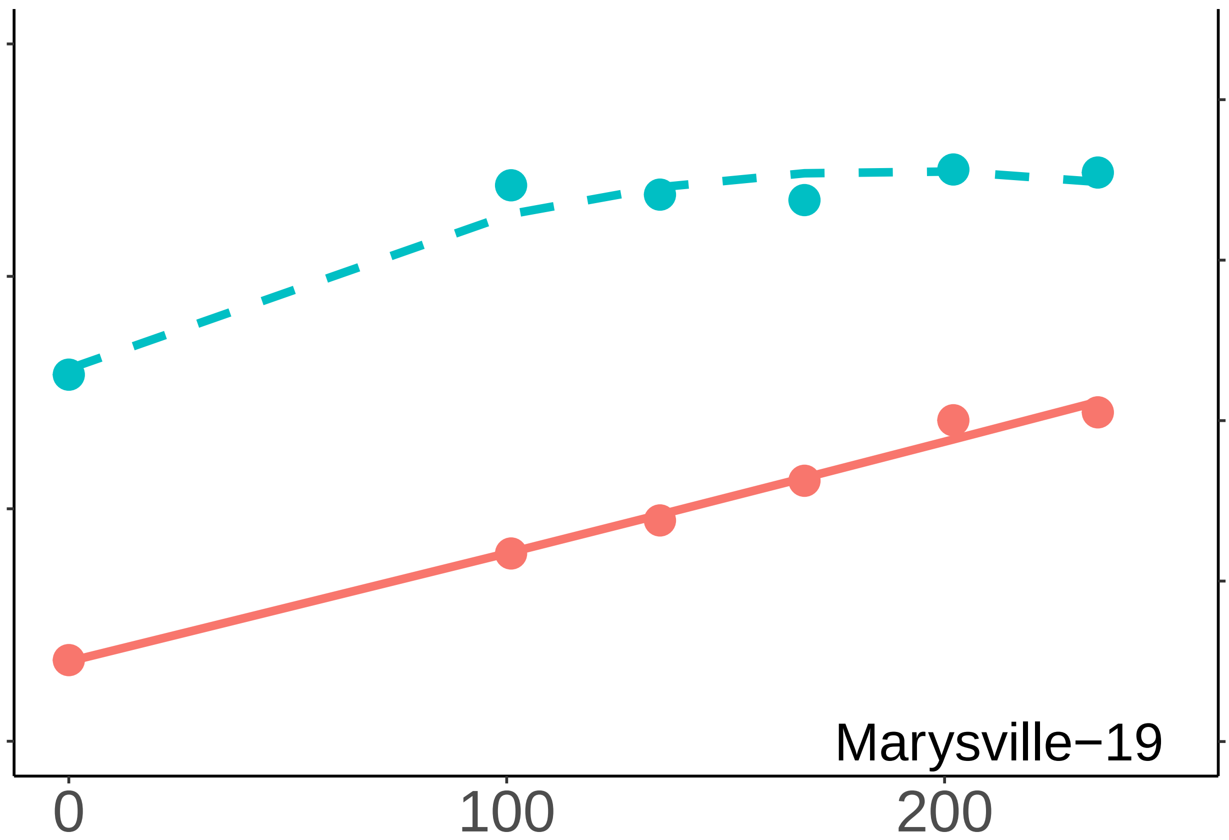
```r
davis19_df_2 <- data.frame(suppl_data1_davis19$N_level_kgha , davis19_fitted_2) #creates dataframe

davis19_plot <- ggplot(data = suppl_data1_davis19 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_davis19 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D"
  geom_point(data = suppl_data1_davis19 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#
  geom_line(data = davis19_df , aes( x = suppl_data1_davis19.N_level_kgha , y = davis19_fitted) , color
  geom_line(data = davis19_df_2 , aes( x = suppl_data1_davis19.N_level_kgha , y = davis19_fitted_2) , c
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 1
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y = element_blank(),
        axis.text.x = element_text(size = 22))+
  annotate("text" , x = 250 , y = 0 , label = "Davis-19" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


davis19_plot
```



Marysville-19

```r
suppl_data1_mry19 <- suppl_data1 %>%
  filter(site_year == "Marysville-19" )

mry19_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_m
```

```r
mry19_fitted <- fitted(mry19_nuptake_lm)
mry19_df <- data.frame(suppl_data1_mry19$N_level_kgha , mry19_fitted) #creates dataframe

mry19_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

mry19_fitted_2 <- (fitted(mry19_yield_lm)*23)
mry19_df_2 <- data.frame(suppl_data1_mry19$N_level_kgha , mry19_fitted_2) #creates dataframe

mry19_plot <- ggplot(data = suppl_data1_mry19 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_mry19 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_mry19 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00B
  geom_line(data = mry19_df , aes( x = suppl_data1_mry19.N_level_kgha , y = mry19_fitted) , color = "#F8
  geom_line(data = mry19_df_2 , aes( x = suppl_data1_mry19.N_level_kgha , y = mry19_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
    scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.x = element_text(size = 22),
        axis.text.y = element_blank()) +
  annotate("text" , x = 250 , y = 0 , label = "Marysville-19" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


mry19_plot
```



RES-19

```
suppl_data1_res19 <- suppl_data1 %>%
  filter(site_year == "RES-19" )

res19_nuptake_lm <- lm(PI_N_Uptake ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_re

res19_fitted <- fitted(res19_nuptake_lm)
res19_df <- data.frame(suppl_data1_res19$N_level_kgha , res19_fitted) #creates dataframe

res19_yield_lm <- lm(GrainYield_Mgha ~ N_level_kgha + I(N_level_kgha*N_level_kgha) , data = suppl_data1_

res19_fitted_2 <- (fitted(res19_yield_lm)*23)
res19_df_2 <- data.frame(suppl_data1_res19$N_level_kgha , res19_fitted_2) #creates dataframe

res19_plot <- ggplot(data = suppl_data1_res19 , aes( x = N_level_kgha , y = PI_N_Uptake)) +
  geom_point(data = suppl_data1_res19 , aes ( x = N_level_kgha , y = PI_N_Uptake) , color = "#F8766D" ,
  geom_point(data = suppl_data1_res19 , aes ( x = N_level_kgha , y = GrainYield_Mgha*23) , color = "#00B
  geom_line(data = res19_df , aes( x = suppl_data1_res19.N_level_kgha , y = res19_fitted) , color = "#F8
  geom_line(data = res19_df_2 , aes( x = suppl_data1_res19.N_level_kgha , y = res19_fitted_2) , color =
  scale_y_continuous(breaks = seq(0 , 300 , by = 100) , sec.axis = sec_axis(~./23  , breaks = seq(0 , 10
  coord_cartesian(ylim = c(0 , 300) , xlim = c(0 , 250)) +
  scale_x_continuous(breaks = seq(0 , 280 , by = 100)) +
  theme_classic() +
  theme(axis.text.y.left = element_blank(),
        axis.text.x = element_text(size = 22),
        axis.text.y.right = element_text(size = 22)) +
  annotate("text" , x = 250 , y = 0 , label = "RES-19" , size = 7 , hjust = 1) +
  labs( x = NULL , y = NULL)


res19_plot
```

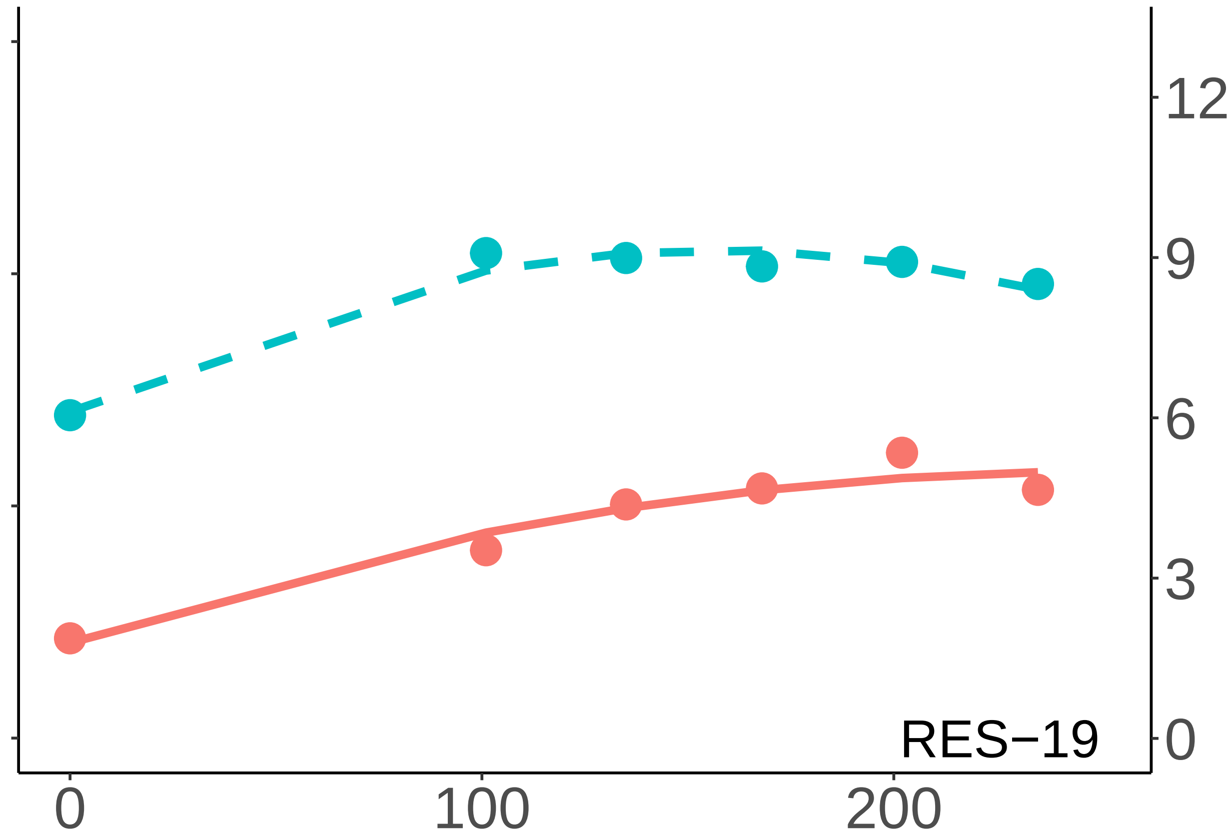
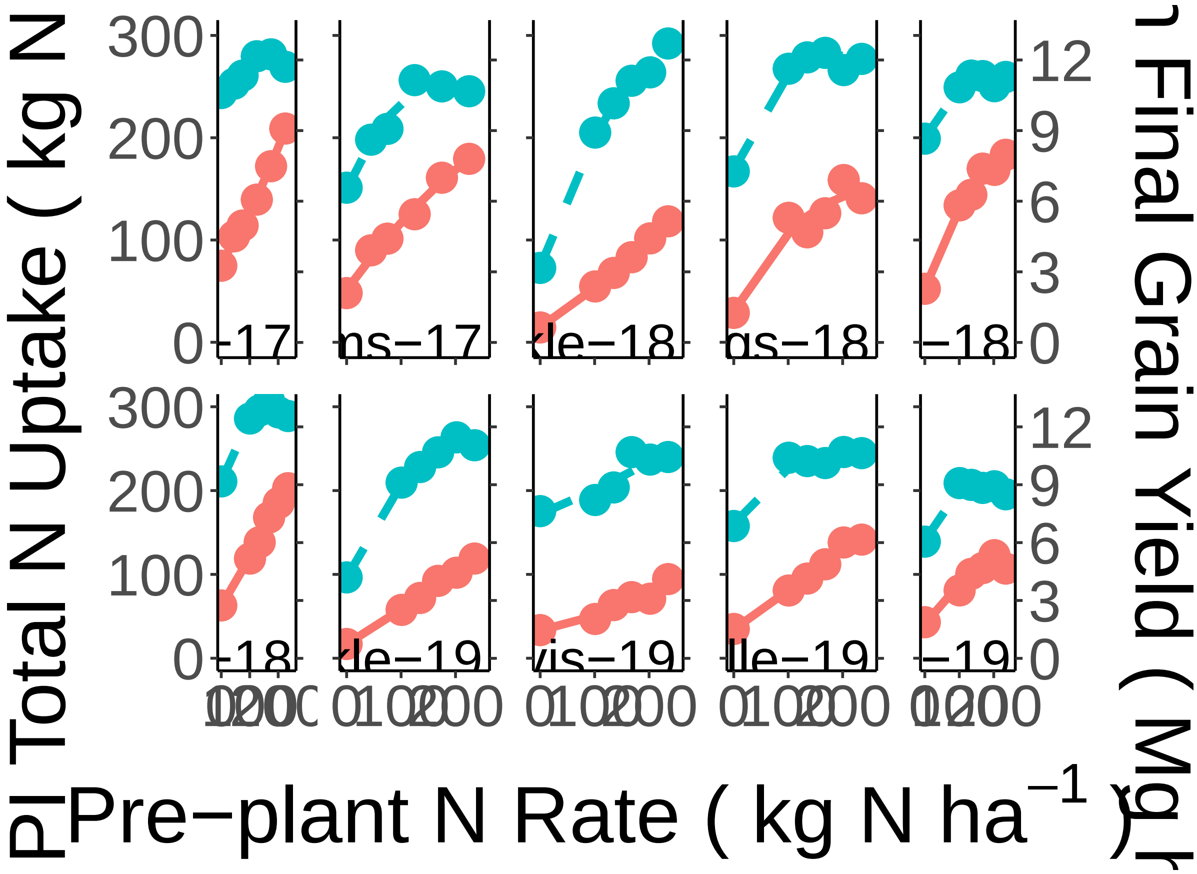
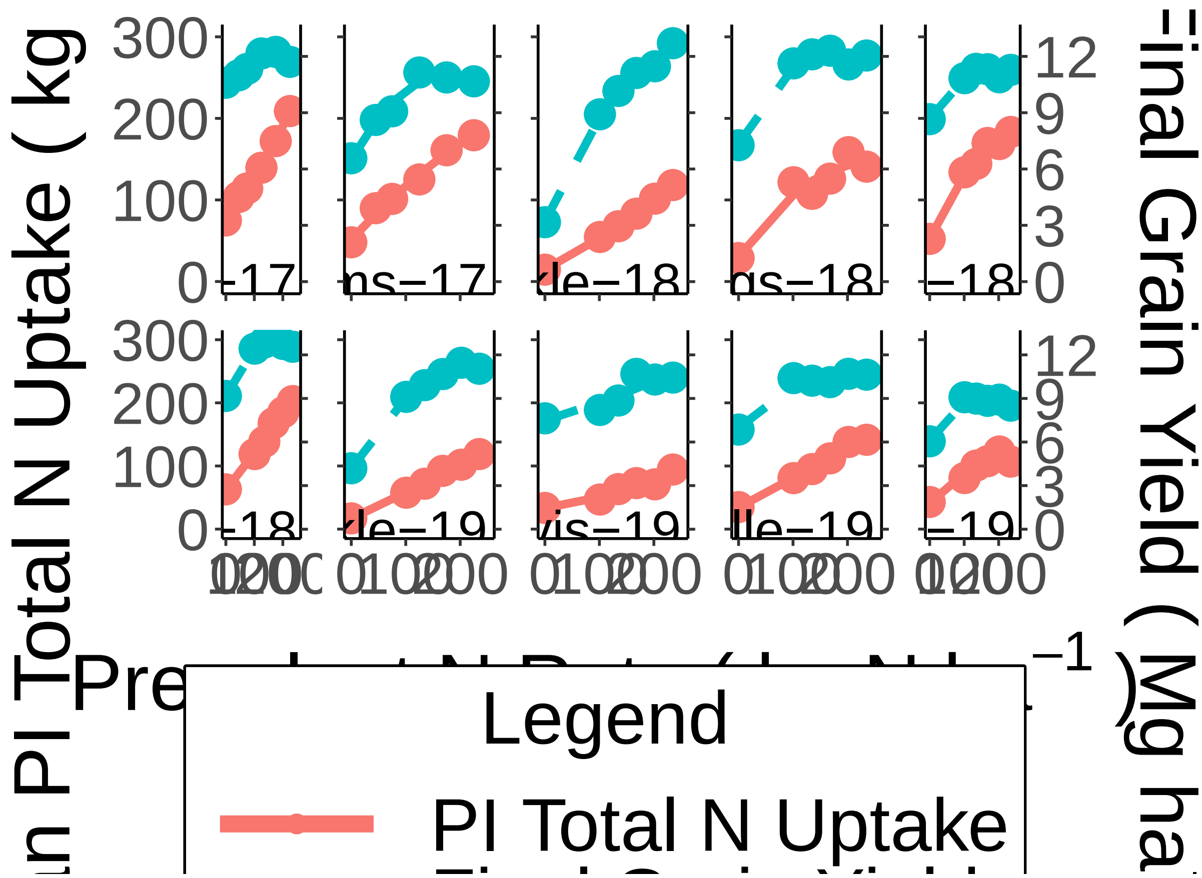


FIGURE 2

```
Fig2 <- grid.arrange(arrangeGrob(
                              nic17_plot,
                              wil17_plot,
                              arb18_plot,
                              biggs18_plot,
                              mry18_plot,
                              nic18_plot,
                              arb19_plot,
                              davis19_plot,
                              mry19_plot,
                              res19_plot,
                              ncol = 5,
                              nrow = 2 ,
                              widths = c(1.4, 1.2 , 1.2, 1.2,  1.3 ),
                              bottom = textGrob("Pre-plant N Rate ( kg N ha"^-1~")" ,
                                                  gp = gpar( fontsize = 30)),
                              right = textGrob("Mean Final Grain Yield ( Mg ha"^-1~")" ,
                                                gp = gpar(fontsize = 30) ,
                                                rot = 270),
                              left = textGrob("Mean PI Total N Uptake ( kg N ha"^-1~")" ,
                                                gp = gpar( fontsize = 30) ,
                                                rot = 90)
                              ))
```




```
Fig2 <- grid.arrange(arrangeGrob(Fig2,
                                  legend,
                                  ncol = 1,
                                  nrow = 2,
                                  heights = c(8 , 1.5)))
```



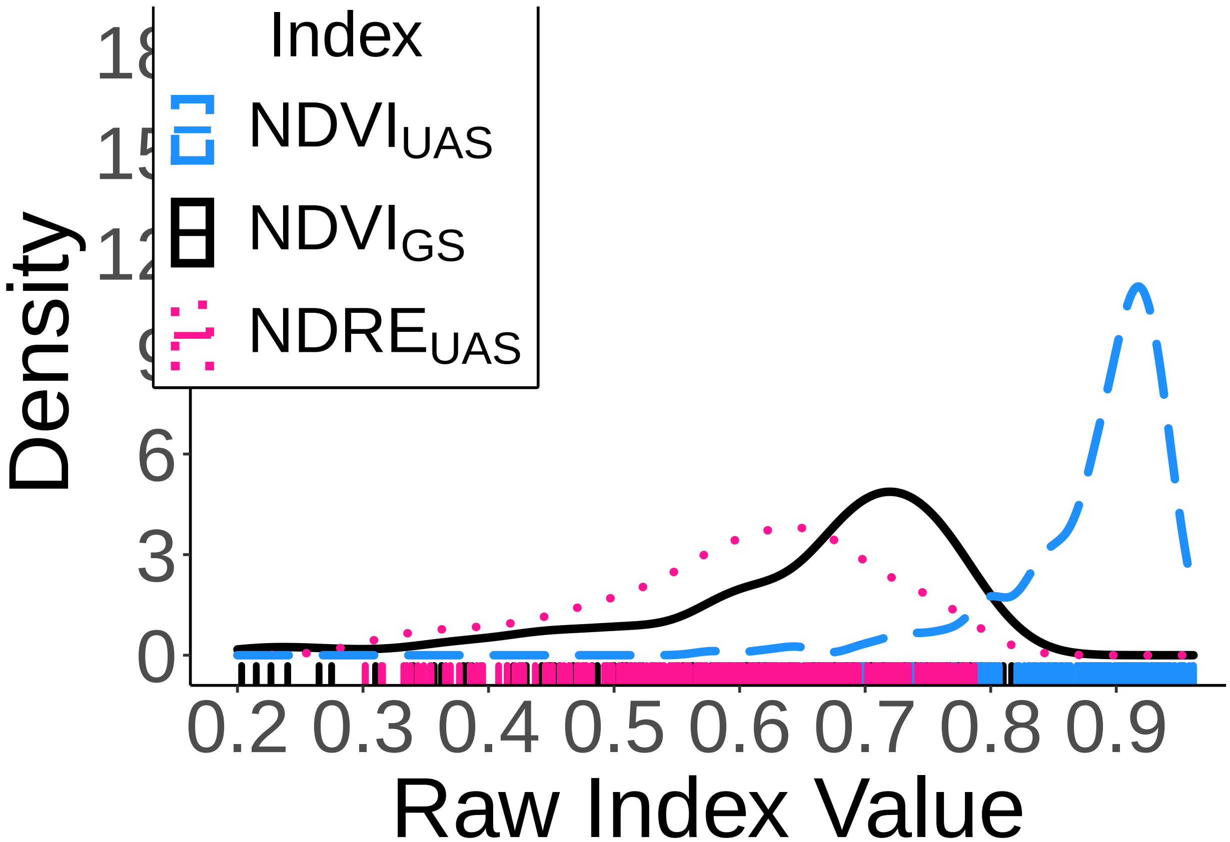

```
ggsave("FIGURES/Fig2.tiff" , Fig2, compression = "lzw" , width = 22 , height = 12 , type = "cairo" , dpi
```

FIGURE 3

IV Kernel

```
Fig3.1 <- ggplot(data = paper3_data , aes(x = Index) ) +
  geom_density(data = paper3_data, aes(x = Index  , color = Platform , linetype = Platform) , size = 1.5
  geom_rug(data = paper3_data , aes(x = Index  , color = Platform) , size = 1.2) +
  theme_classic() +
  theme(axis.title = element_text(size = 32),
        axis.text = element_text(size = 28),
        legend.text = element_text(size = 24),
        legend.title = element_text(size = 24 , hjust = 0.5),
        legend.position = c(.15 , .75),
        legend.text.align = 0,
        legend.box.background = element_rect(size = 1)) +
  coord_cartesian(xlim = c(0.2 , 0.95)  ,ylim = c(0 , 18)) +
  scale_x_continuous(breaks = seq(.2 , .9 , by = .1)) +
  scale_y_continuous(breaks = seq(0 , 18 , by = 3)) +
  labs(x = "Raw Index Value" , y = "Density" , color = "Index" , linetype = "Index") +
  scale_color_manual(breaks = c("sUAS NDVI" , "GreenSeeker NDVI" ,  "sUAS NDRE") , values = c( "dodgerbl
  scale_linetype_manual(breaks = c("sUAS NDVI" , "GreenSeeker NDVI" ,  "sUAS NDRE") , values = c("longda
    guides(
    color = guide_legend(byrow = TRUE)
  ) +
```

```
  theme(
        legend.spacing.y = unit(0.4, "cm")) +
  annotate("text" , x = (0.2) , y = (18) , label = "(a)" , size = 10 , hjust = 0.5 , fontface = 2)

Fig3.1
```

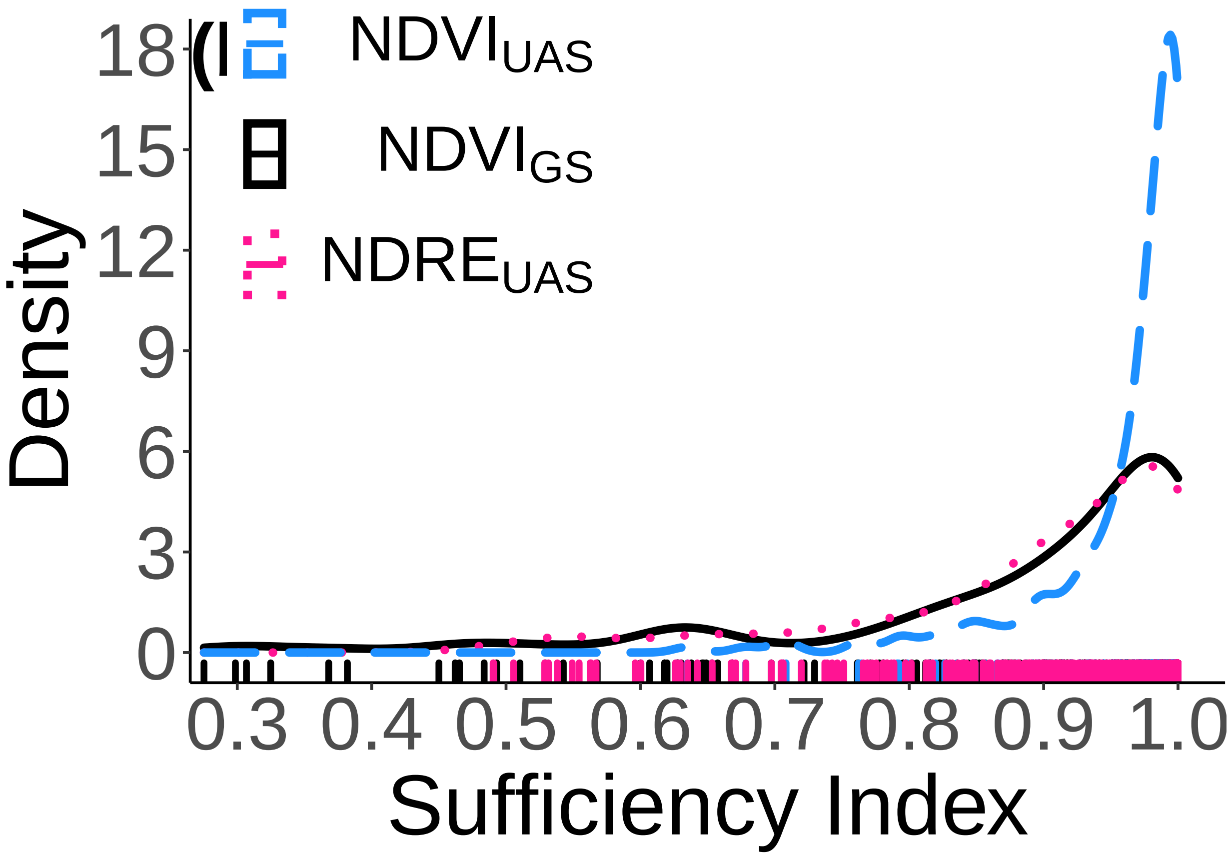



```
ggsave("FIGURES/Fig3.1.tiff" , Fig3.1 , compression = "lzw" , width = 15 , height = 10, type = "cairo"
```

SI Kernel

```
Fig3.2 <- ggplot(data = paper3_data , aes(x = SI) ) +
  geom_density(data = paper3_data, aes(x = SI  , color = Platform , linetype = Platform) , size = 1.5) +
  geom_rug(data = paper3_data , aes(x = SI  , color = Platform) , size = 1.2) +
  theme_classic() +
  theme(axis.title = element_text(size = 32),
        axis.text = element_text(size = 28),
        legend.text = element_text(size = 24),
        legend.title = element_text(size = 24),
        legend.position = c(0.22 , 0.87)
        ) +
  coord_cartesian(xlim = c(.3 , 1) , ylim = c(0 , 18)) +
  scale_x_continuous(breaks = seq(.3 , 1 , by = .1)) +
  scale_y_continuous(breaks = seq(0 , 18 , by = 3)) +
  labs(x = "Sufficiency Index" , y = "Density" , color = "Index" , linetype = "Index") +
  scale_color_manual(breaks = c("sUAS NDVI" , "GreenSeeker NDVI" ,  "sUAS NDRE") , values = c( "dodgerbl
```

```
  scale_linetype_manual(breaks = c("sUAS NDVI" , "GreenSeeker NDVI" ,  "sUAS NDRE") , values = c("longda
    guides(
    color = guide_legend(byrow = TRUE)
  ) +
  theme(
        legend.spacing.y = unit(0.5, "cm")) +
  annotate("text" , x = (0.3) , y = (18) , label = "(b)" , size = 10 , hjust = 0.5 , fontface = 2)


Fig3.2
```

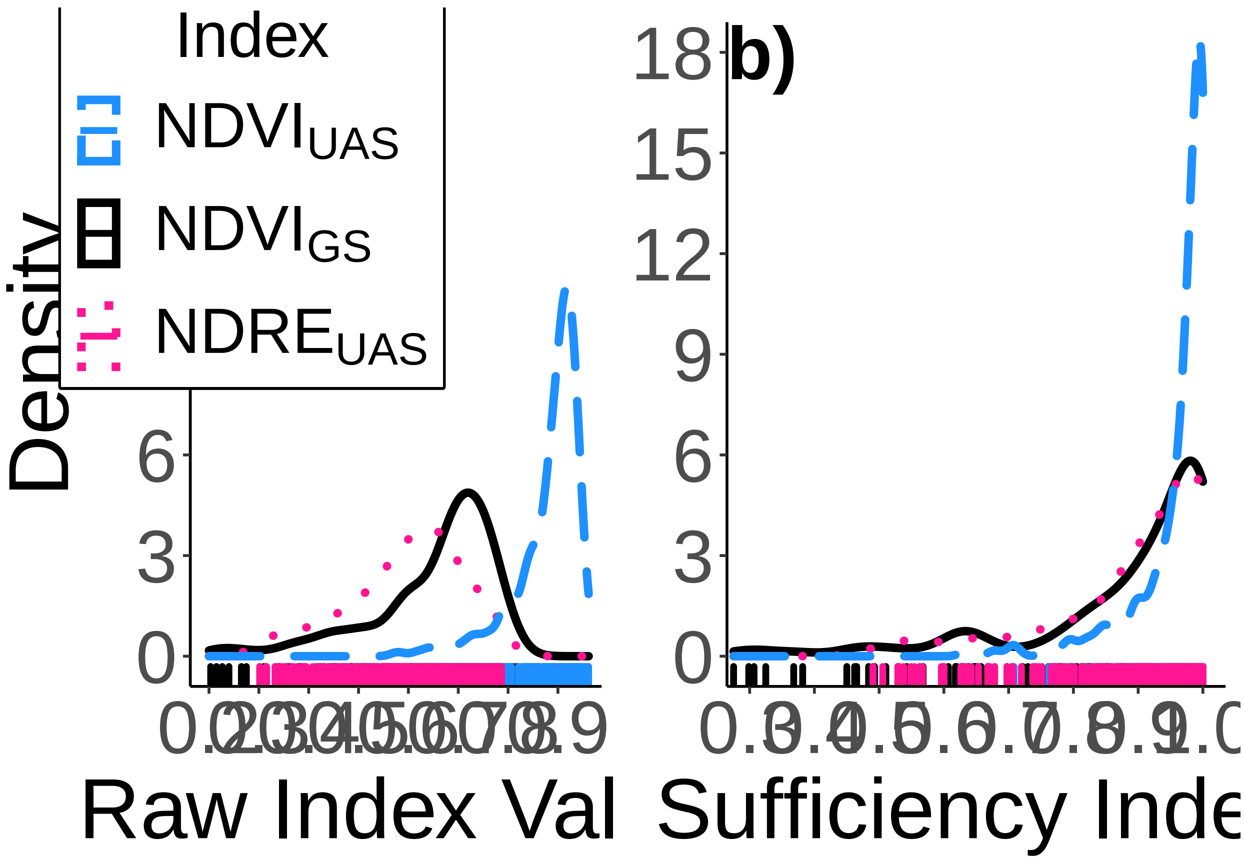



```
ggsave("FIGURES/Fig3.2.tiff" , Fig3.2 , compression = "lzw" , width = 15 , height = 10, type = "cairo"

Fig3.2.2 <- Fig3.2 +
  labs(x = "Sufficiency Index" , y = NULL , color = "Index" , linetype = "Index") +
    theme(axis.title = element_text(size = 32),
        axis.text = element_text(size = 28),
        legend.text = element_text(size = 24),
        legend.title = element_text(size = 24),
        legend.position = "none"
        )
```

FIGURE 3

```
Fig3 <- grid.arrange(arrangeGrob(Fig3.1,
                                 Fig3.2.2,
```

```
                                  nrow = 1,
                                  ncol = 2
                                  ))
```




```
ggsave("FIGURES/Fig3.tiff" , Fig3 , compression = "lzw" , width = 20 , height = 10, type = "cairo" , dpi
```

FIGURE 4

gs-ndvi-SI

```
fit.lm    <- lm(SI ~ PI_N_Uptake, data= paper3_gsdata)

a.ini     <- fit.lm$coefficients[1]
b.ini     <- fit.lm$coefficients[2]
clx.ini   <- mean(paper3_gsdata$PI_N_Uptake)

quadplat <- function(x, a, b, clx) {
           ifelse(x  < clx, a + b * x   + (-0.5*b/clx) * x   * x,
                            a + b * clx + (-0.5*b/clx) * clx * clx)}

model <- nls(SI ~ quadplat(PI_N_Uptake, a, b, clx),
            data = paper3_gsdata,
            start = list(a   = a.ini,
                         b   = b.ini,
                         clx = clx.ini),
             trace = FALSE,
```

```r
            nls.control(maxiter = 1000))

summary(model)
```

```
##
## Formula: SI ~ quadplat(PI_N_Uptake, a, b, clx)
##
## Parameters:
##      Estimate Std. Error t value Pr(>|t|)
## a   2.197e-01  3.757e-02   5.848 1.66e-08 ***
## b   1.318e-02  1.103e-03  11.946  < 2e-16 ***
## clx 1.126e+02  4.922e+00  22.868  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.08152 on 234 degrees of freedom
##
## Number of iterations to convergence: 9
## Achieved convergence tolerance: 4.188e-06
```

```r
nullfunct <- function(x, m){m}

m.ini    <- mean(paper3_gsdata$SI)

null <- nls(SI ~ nullfunct(PI_N_Uptake, m),
           data = paper3_gsdata,
           start = list(m    = m.ini),
           trace = FALSE,
           nls.control(maxiter = 1000))

nagelkerke(model,
           null)
```

```
## $Models
##
## Model: "nls, SI ~ quadplat(PI_N_Uptake, a, b, clx), paper3_gsdata, list(a = a.ini, b = b.ini, clx = c
## Null:  "nls, SI ~ nullfunct(PI_N_Uptake, m), paper3_gsdata, list(m = m.ini), list(1000, 1e-05, 0.000
##
## $Pseudo.R.squared.for.model.vs.null
##                              Pseudo.R.squared
## McFadden                            -1.478860
## Cox and Snell (ML)                   0.729047
## Nagelkerke (Cragg and Uhler)        -0.514101
##
## $Likelihood.ratio.test
##  Df.diff LogLik.diff  Chisq    p.value
##       -2     -154.74 309.48 6.2806e-68
##
## $Number.of.observations
##
## Model: 237
## Null:  237
##
## $Messages
```

```
## [1] "Note: For models fit with REML, these statistics are based on refitting with ML"
##
## $Warnings
## [1] "None"
```

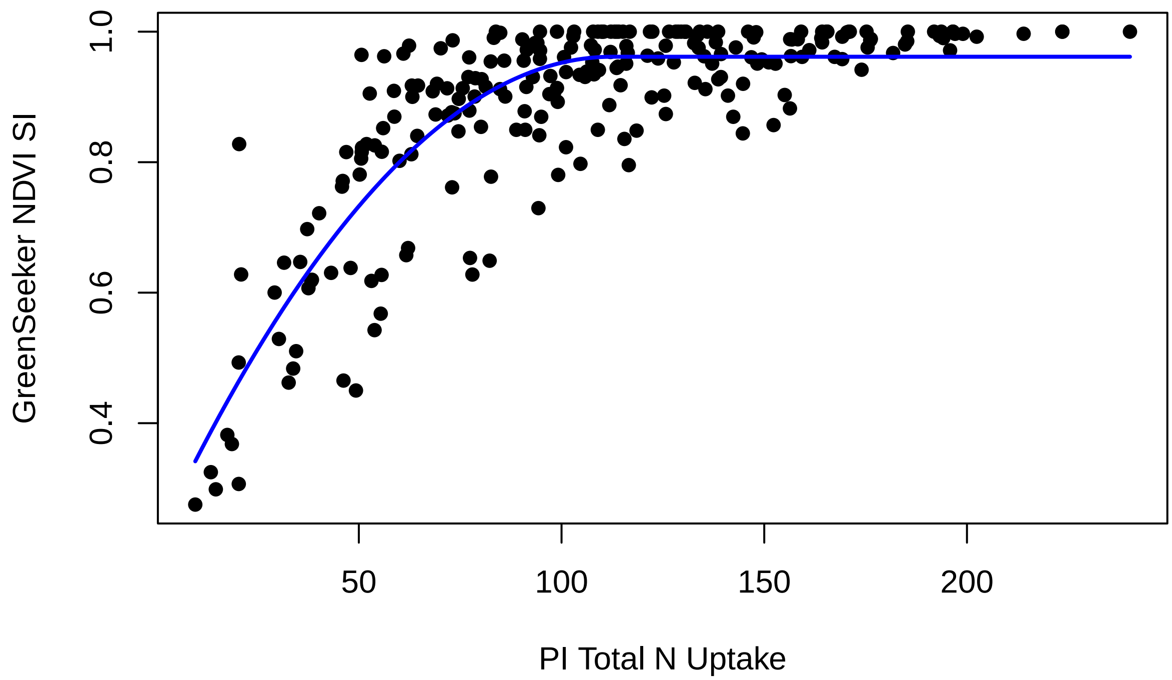
```
confint2(model,
         level = 0.95)
```

```
##            2.5 %       97.5 %
## a     0.14569776   0.29373689
## b     0.01100811   0.01535621
## clx 102.86320065 122.25856538
```

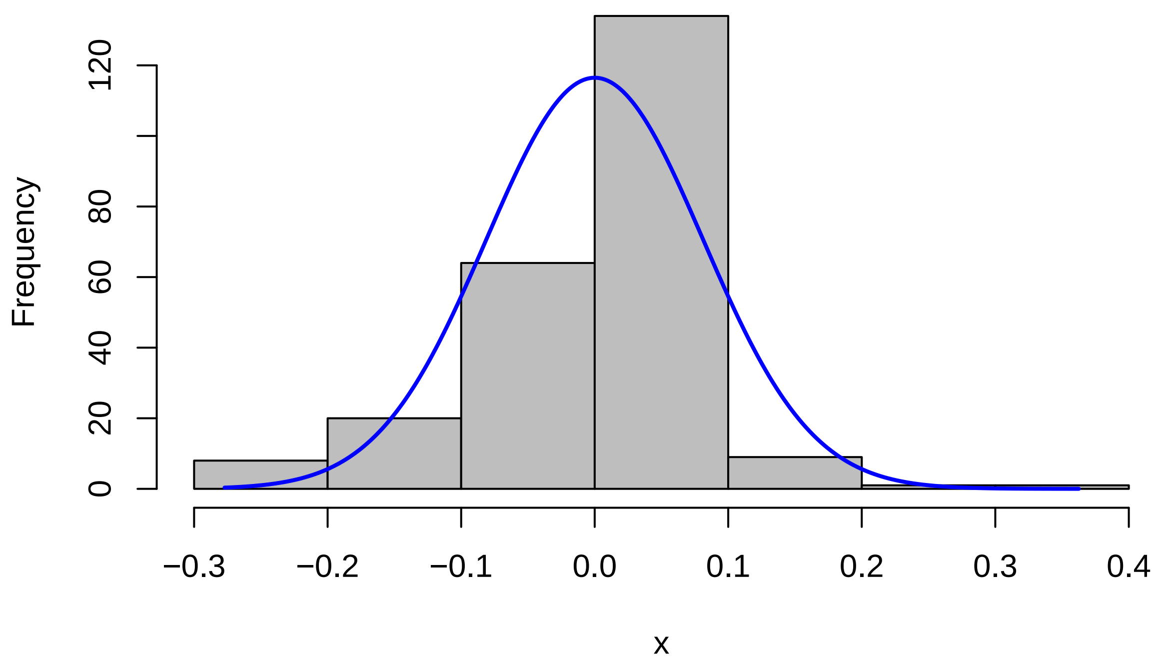
```
Boot <- nlsBoot(model)

summary(Boot)
```

```
##
## ------
## Bootstrap statistics
##         Estimate  Std. error
## a     0.21842721 0.037845938
## b     0.01323534 0.001087453
## clx 112.72543911 4.725630630
##
## ------
## Median of bootstrap estimates and percentile confidence intervals
##          Median         2.5%        97.5%
## a     0.2195034   0.13939037   0.28764331
## b     0.0131886   0.01126011   0.01548387
## clx 112.7423863 103.67475871 122.03782922
```

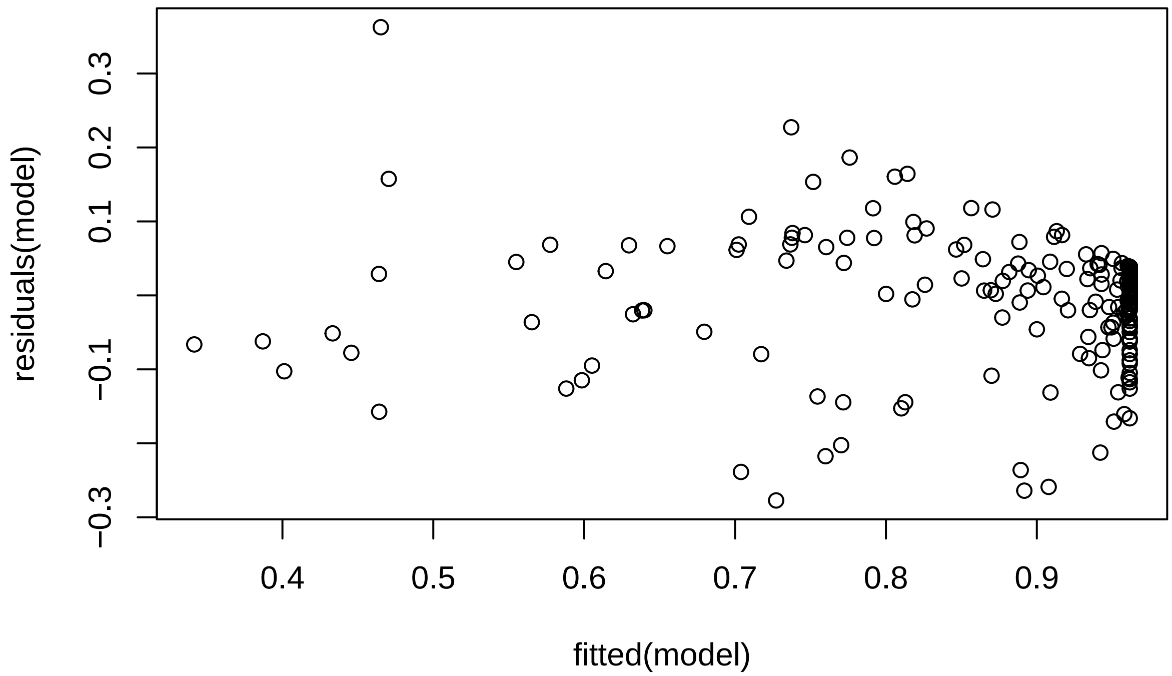
```
plotPredy(data  = paper3_gsdata,
          x     = PI_N_Uptake,
          y     = SI,
          model = model,
          xlab  = "PI Total N Uptake",
          ylab  = "GreenSeeker NDVI SI")
```




```
x <- residuals(model)

plotNormalHistogram(x)
```




```
plot(fitted(model),
     residuals(model))
```

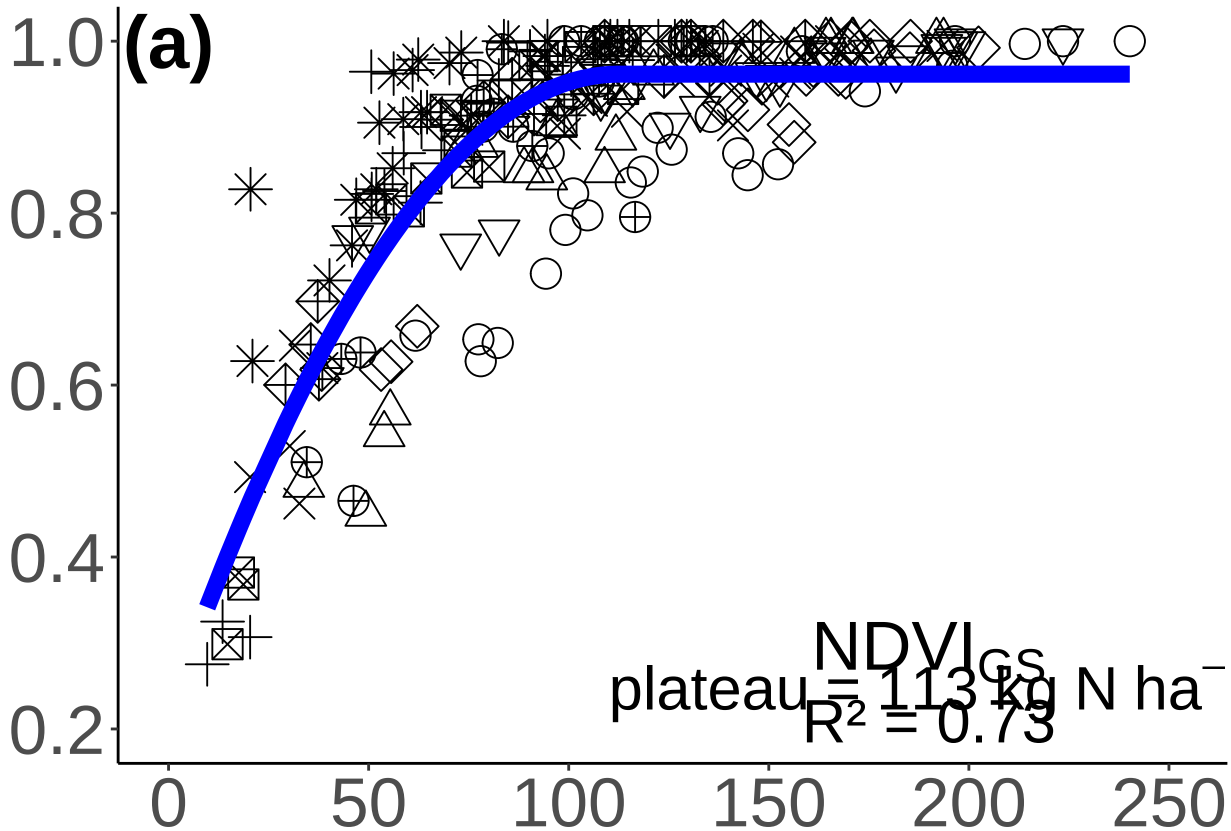



```
a <- summary(model)$coefficients[1]
b <- summary(model)$coefficients[2]
clx <- summary(model)$coefficients[3]

plateau <- a + b * clx + (-0.5*b)*clx
plateau
```

```
## [1] 0.9616152
```

```
GS_ndvi_fit_quadplat <- fitted(model)
GS_ndvi_quadplat_df <- data.frame(paper3_gsdata$PI_N_Uptake , GS_ndvi_fit_quadplat) #creates dataframe
```

```
GS_ndvi_si_quad_plot <- ggplot(data = paper3_gsdata , aes ( x = PI_N_Uptake , y = SI)) +
  geom_point(data = paper3_gsdata , aes ( x = PI_N_Uptake , y = SI , shape = site_year) , size = 5) +
  geom_line(data = GS_ndvi_quadplat_df , aes( x = paper3_gsdata.PI_N_Uptake , y = GS_ndvi_fit_quadplat)
  coord_cartesian(ylim = c(0.20 , 1) , xlim = c(0 , 252)) +
  scale_x_continuous(breaks = seq(0 , 250 , by = 50)) +
  theme_classic() +
  labs(x = NULL , y = NULL) +
  annotate("text", x = 0 , y = 1, label = "(a)", size = 10 , color = "black" , hjust = .5 , fontface = 2
  annotate("text", x = 190 , y = .29, label = "NDVI[GS]", size = 9 , color = "black" , hjust = .5 , pars
  annotate("text", x = 190 , y = .25, label = "plateau~'='~113~kg~N~ha^-1", size = 8 , color = "black"
  annotate("text", x = 190 , y = .21, label = "R² = 0.73", size = 8 , color = "black"  , hjust = .5) +
  theme(axis.title = element_text(size = 26),
        axis.text = element_text(size = 26),
        legend.text = element_text(size = 24),
        legend.title = element_text(size = 24)
        ) +
  geom_hline(yintercept = 0 , size = 0.75) +
  theme(legend.position = "none") +
  scale_shape_manual(values = c(1:20))

GS_ndvi_si_quad_plot
```



suas-ndre-SI

```
fit.lm2     <- lm(SI ~ PI_N_Uptake, data= paper3_uas_ndre_data)

a.ini2      <- fit.lm2$coefficients[1]
b.ini2      <- fit.lm2$coefficients[2]
clx.ini2    <- mean(paper3_uas_ndre_data$PI_N_Uptake)

quadplat <- function(x, a, b, clx) {
           ifelse(x  < clx, a + b * x   + (-0.5*b/clx) * x   * x,
                            a + b * clx + (-0.5*b/clx) * clx * clx)}

model2 <- nls(SI ~ quadplat(PI_N_Uptake, a, b, clx),
            data = paper3_uas_ndre_data,
            start = list(a   = a.ini2,
                         b   = b.ini2,
                         clx = clx.ini2),
             trace = FALSE,
             nls.control(maxiter = 1000))

summary(model2)
```

```
##
## Formula: SI ~ quadplat(PI_N_Uptake, a, b, clx)
##
## Parameters:
##      Estimate Std. Error t value Pr(>|t|)
```

```
## a   3.996e-01  2.280e-02   17.52   <2e-16 ***
## b   8.840e-03  5.969e-04   14.81   <2e-16 ***
## clx 1.287e+02  4.863e+00   26.48   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.05606 on 234 degrees of freedom
##
## Number of iterations to convergence: 7
## Achieved convergence tolerance: 5.347e-06
```

```
nullfunct <- function(x, m){m}

m.ini2    <- mean(paper3_uas_ndre_data$SI)

null2 <- nls(SI ~ nullfunct(PI_N_Uptake, m),
           data = paper3_uas_ndre_data,
           start = list(m    = m.ini2),
           trace = FALSE,
           nls.control(maxiter = 1000))

nagelkerke(model2,
           null2)
```

```
## $Models
##
## Model: "nls, SI ~ quadplat(PI_N_Uptake, a, b, clx), paper3_uas_ndre_data, list(a = a.ini2, b = b.ini2
## Null:  "nls, SI ~ nullfunct(PI_N_Uptake, m), paper3_uas_ndre_data, list(m = m.ini2), list(1000, 1e-05
##
## $Pseudo.R.squared.for.model.vs.null
##                              Pseudo.R.squared
## McFadden                            -1.197260
## Cox and Snell (ML)                   0.798212
## Nagelkerke (Cragg and Uhler)        -0.284368
##
## $Likelihood.ratio.test
##  Df.diff LogLik.diff  Chisq    p.value
##       -2     -189.66 379.33 4.2675e-83
##
## $Number.of.observations
##
## Model: 237
## Null:  237
##
## $Messages
## [1] "Note: For models fit with REML, these statistics are based on refitting with ML"
##
## $Warnings
## [1] "None"
```

```
confint2(model2,
        level = 0.95)
```

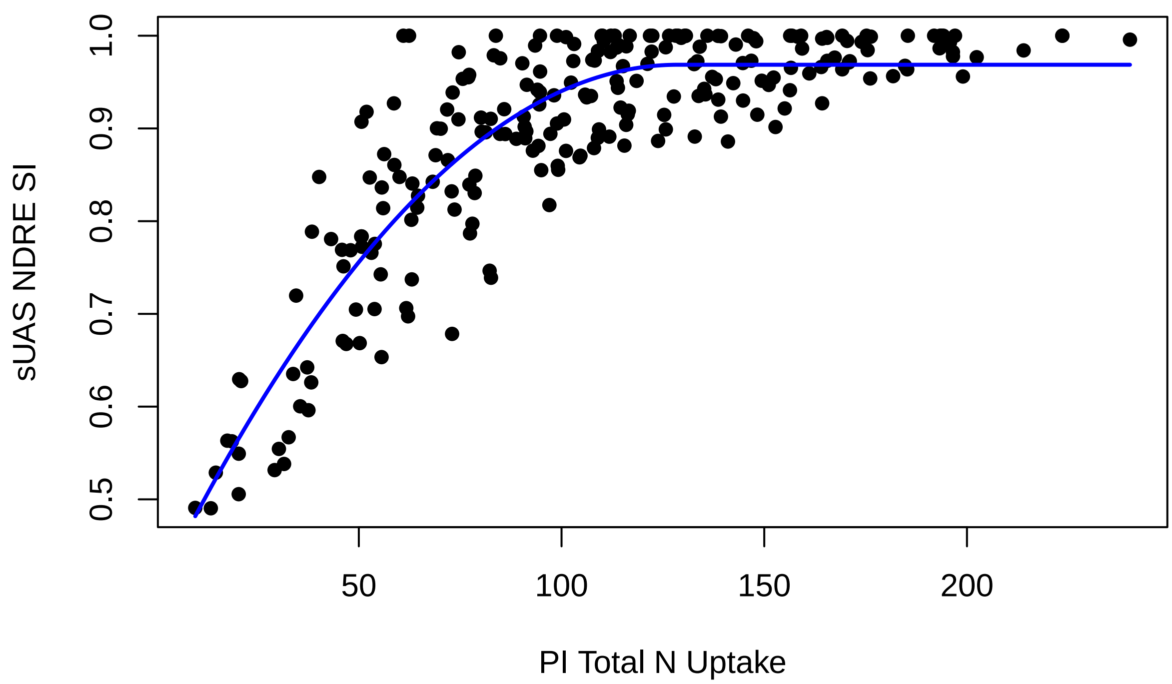
```
##            2.5 %       97.5 %
## a     0.35471353   0.44456994
## b     0.00766395   0.01001592
```

```
## clx 119.16598951 138.32655129
```

```r
Boot2 <- nlsBoot(model2)

summary(Boot2)
```

```
##
## ------
## Bootstrap statistics
##          Estimate   Std. error
## a      0.39834727 0.0228277056
## b      0.00888344 0.0005930768
## clx 128.67463380 4.8279270730
##
## ------
## Median of bootstrap estimates and percentile confidence intervals
##            Median          2.5%        97.5%
## a   3.998598e-01 3.511902e-01   0.44259004
## b   8.855489e-03 7.793527e-03   0.01009698
## clx 1.284738e+02 1.199725e+02 138.73898403
```

```r
plotPredy(data  = paper3_uas_ndre_data,
          x     = PI_N_Uptake,
          y     = SI,
          model = model2,
          xlab  = "PI Total N Uptake",
          ylab  = "sUAS NDRE SI")
```

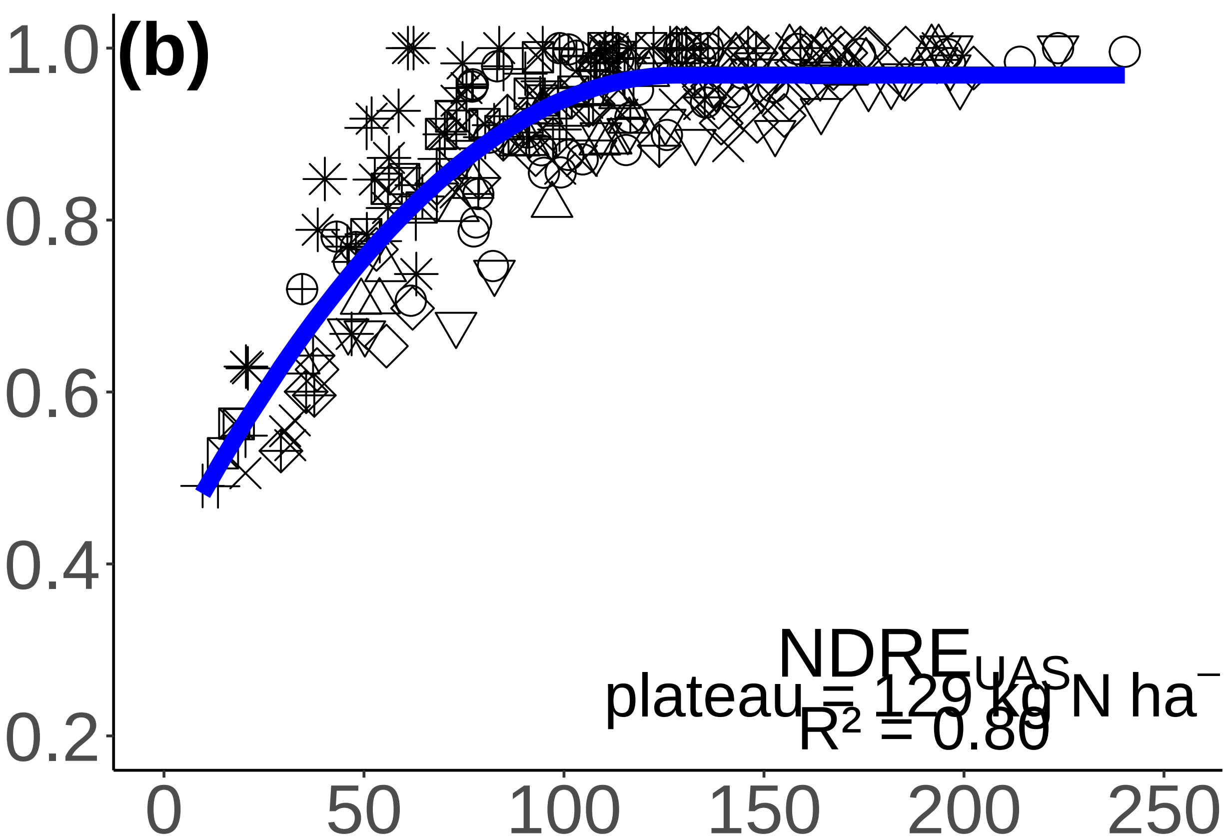



```r
a2 <- summary(model2)$coefficients[1]
b2 <- summary(model2)$coefficients[2]
clx2 <- summary(model2)$coefficients[3]

plateau2 <- a2 + b2 * clx2 + (-0.5*b2)*clx2
plateau2
```

```
## [1] 0.9686962
```

```
sUAS_ndre_fit_quadplat <- fitted(model2)
sUAS_ndre_quadplat_df <- data.frame(paper3_uas_ndre_data$PI_N_Uptake , sUAS_ndre_fit_quadplat) #creates
```

```
suas_ndre_si_quad_plot <- ggplot(data = paper3_uas_ndre_data , aes ( x = PI_N_Uptake , y = SI)) +
  geom_point(data = paper3_uas_ndre_data , aes ( x = PI_N_Uptake , y = SI , shape = site_year) , size =
  geom_line(data = sUAS_ndre_quadplat_df , aes( x = paper3_uas_ndre_data.PI_N_Uptake , y = sUAS_ndre_fi
  coord_cartesian(ylim = c(0.20 , 1) , xlim = c(0 , 252)) +
  scale_x_continuous(breaks = seq(0 , 250 , by = 50)) +
  theme_classic() +
  labs(x = NULL , y = NULL) +
  annotate("text", x = 0 , y = 1, label = "(b)", size = 10 , color = "black" , hjust = 0.5 , fontface =
  annotate("text", x = 190 , y = .29, label = "NDRE[UAS]", size = 9 , color = "black" , hjust = .5 , pa
  annotate("text", x = 190 , y = .25, label = "plateau~'='~129~kg~N~ha^-1", size = 8 , color = "black"
  annotate("text", x = 190 , y = .21, label = "R² = 0.80", size = 8 , color = "black"  , hjust = .5) +
  theme(axis.title = element_text(size = 26),
        axis.text = element_text(size = 26),
        legend.text = element_text(size = 24),
        legend.title = element_text(size = 24)
        ) +
  geom_hline(yintercept = 0 , size = 0.75) +
  theme(legend.position = "none") +
  scale_shape_manual(values = c(1:20))

suas_ndre_si_quad_plot
```



suas-ndvi-SI

```
fit.lm3    <- lm(SI ~ PI_N_Uptake, data= paper3_uas_ndvi_data)

a.ini3     <- fit.lm3$coefficients[1]
b.ini3     <- fit.lm3$coefficients[2]
clx.ini3   <- mean(paper3_uas_ndvi_data$PI_N_Uptake)

quadplat <- function(x, a, b, clx) {
           ifelse(x  < clx, a + b * x   + (-0.5*b/clx) * x   * x,
                            a + b * clx + (-0.5*b/clx) * clx * clx)}

model3 <- nls(SI ~ quadplat(PI_N_Uptake, a, b, clx),
            data = paper3_uas_ndvi_data,
            start = list(a   = a.ini3,
                         b   = b.ini3,
                         clx = clx.ini3),
             trace = FALSE,
             nls.control(maxiter = 1000))

summary(model3)
```

```
##
## Formula: SI ~ quadplat(PI_N_Uptake, a, b, clx)
##
## Parameters:
##      Estimate Std. Error t value Pr(>|t|)
## a   6.458e-01  1.403e-02   46.02   <2e-16 ***
## b   7.078e-03  4.723e-04   14.99   <2e-16 ***
## clx 9.646e+01  3.180e+00   30.34   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.02632 on 234 degrees of freedom
##
## Number of iterations to convergence: 11
## Achieved convergence tolerance: 7.936e-06
```

```
nullfunct <- function(x, m){m}

m.ini3    <- mean(paper3_uas_ndvi_data$SI)

null3 <- nls(SI ~ nullfunct(PI_N_Uptake, m),
           data = paper3_uas_ndvi_data,
           start = list(m   = m.ini3),
           trace = FALSE,
           nls.control(maxiter = 1000))

nagelkerke(model3,
           null3)
```

```
## $Models
##
## Model: "nls, SI ~ quadplat(PI_N_Uptake, a, b, clx), paper3_uas_ndvi_data, list(a = a.ini3, b = b.ini3
## Null:  "nls, SI ~ nullfunct(PI_N_Uptake, m), paper3_uas_ndvi_data, list(m = m.ini3), list(1000, 1e-05
```

```
##
## $Pseudo.R.squared.for.model.vs.null
##                              Pseudo.R.squared
## McFadden                            -0.605012
## Cox and Snell (ML)                   0.813116
## Nagelkerke (Cragg and Uhler)        -0.054225
##
## $Likelihood.ratio.test
##  Df.diff LogLik.diff  Chisq    p.value
##       -2     -198.76 397.51 4.7998e-87
##
## $Number.of.observations
##
## Model: 237
## Null:  237
##
## $Messages
## [1] "Note: For models fit with REML, these statistics are based on refitting with ML"
##
## $Warnings
## [1] "None"
```

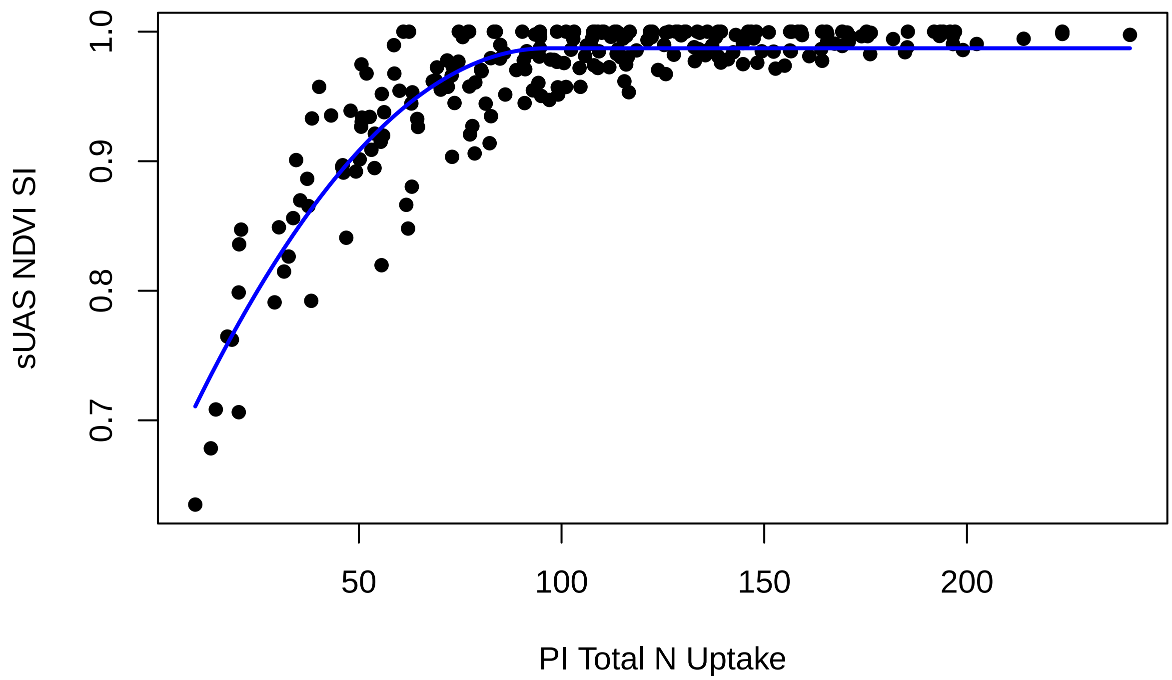
```
confint2(model3,
         level = 0.95)
```

```
##            2.5 %       97.5 %
## a    0.618157809 6.734574e-01
## b    0.006147996 8.008987e-03
## clx 90.196205891 1.027258e+02
```

```
Boot3 <- nlsBoot(model3)

summary(Boot3)
```

```
##
## ------
## Bootstrap statistics
##        Estimate   Std. error
## a    0.64458101 0.0140131539
## b    0.00712298 0.0004710038
## clx 96.40076649 3.1039897943
##
## ------
## Median of bootstrap estimates and percentile confidence intervals
##           Median         2.5%        97.5%
## a    0.645410303  0.616728996 6.698013e-01
## b    0.007100738  0.006275563 8.070276e-03
## clx 96.344508975 90.543489243 1.026824e+02
```

```
plotPredy(data  = paper3_uas_ndvi_data,
          x     = PI_N_Uptake,
          y     = SI,
          model = model3,
          xlab  = "PI Total N Uptake",
          ylab  = "sUAS NDVI SI")
```




```r
a3 <- summary(model3)$coefficients[1]
b3 <- summary(model3)$coefficients[2]
clx3 <- summary(model3)$coefficients[3]

plateau3 <- a3 + b3 * clx3 + (-0.5*b3)*clx3
plateau3
```

```
## [1] 0.9872068
```

```r
sUAS_ndvi_fit_quadplat <- fitted(model3)
sUAS_ndvi_quadplat_df <- data.frame(paper3_uas_ndvi_data$PI_N_Uptake , sUAS_ndvi_fit_quadplat) #creates
```

```r
suas_ndvi_si_quad_plot <- ggplot(data = paper3_uas_ndvi_data , aes ( x = PI_N_Uptake , y = SI)) +
  geom_point(data = paper3_uas_ndvi_data , aes ( x = PI_N_Uptake , y = SI , shape = site_year) , size =
  geom_line(data = sUAS_ndvi_quadplat_df , aes( x = paper3_uas_ndvi_data.PI_N_Uptake , y = sUAS_ndvi_fi
  coord_cartesian(ylim = c(0.20 , 1) , xlim = c(0 , 252)) +
  scale_x_continuous(breaks = seq(0 , 250 , by = 50)) +
  theme_classic() +
  labs(x = NULL , y = NULL , shape = "Site-Year") +
  annotate("text", x = 0 , y = 1, label = "(c)", size = 10 , color = "black" , hjust = 0.5 , fontface =
  annotate("text", x = 190 , y = .29, label = "NDVI[UAS]", size = 9 , color = "black" , hjust = .5 , pa
  annotate("text", x = 190 , y = .25, label = "plateau~'='~96~kg~N~ha^-1", size = 8 , color = "black" ,
  annotate("text", x = 190 , y = .21, label = "R² = 0.81", size = 8 , color = "black"  , hjust = .5) +
  theme(axis.title = element_text(size = 26),
        axis.text = element_text(size = 26),
        legend.text = element_text(size = 20),
        legend.title = element_text(size = 20 , hjust = 0.5),
        legend.box.background = element_rect(size = 1)) +
  geom_hline(yintercept = 0 , size = 0.75) +
  theme(legend.position = c(.72 , .4)) +
  scale_shape_manual(values = c(1:20))

suas_ndvi_si_quad_plot
```

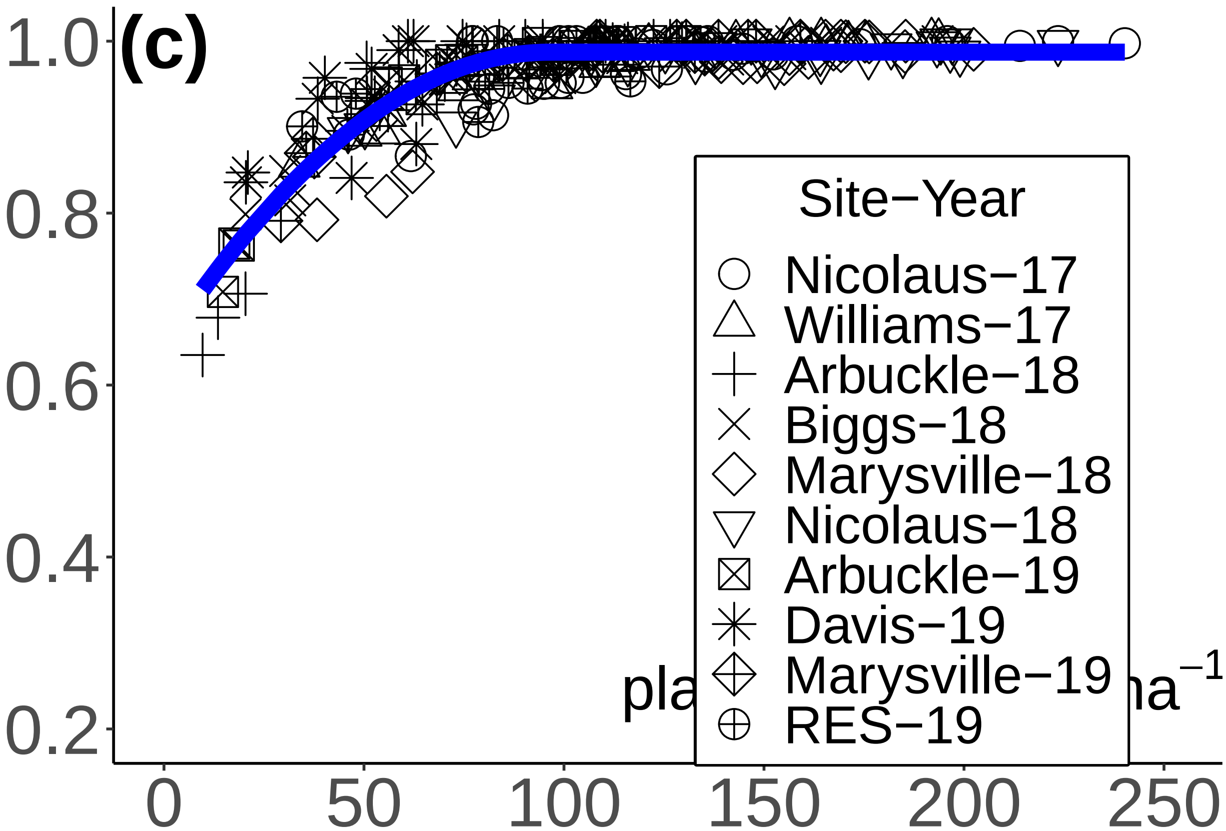
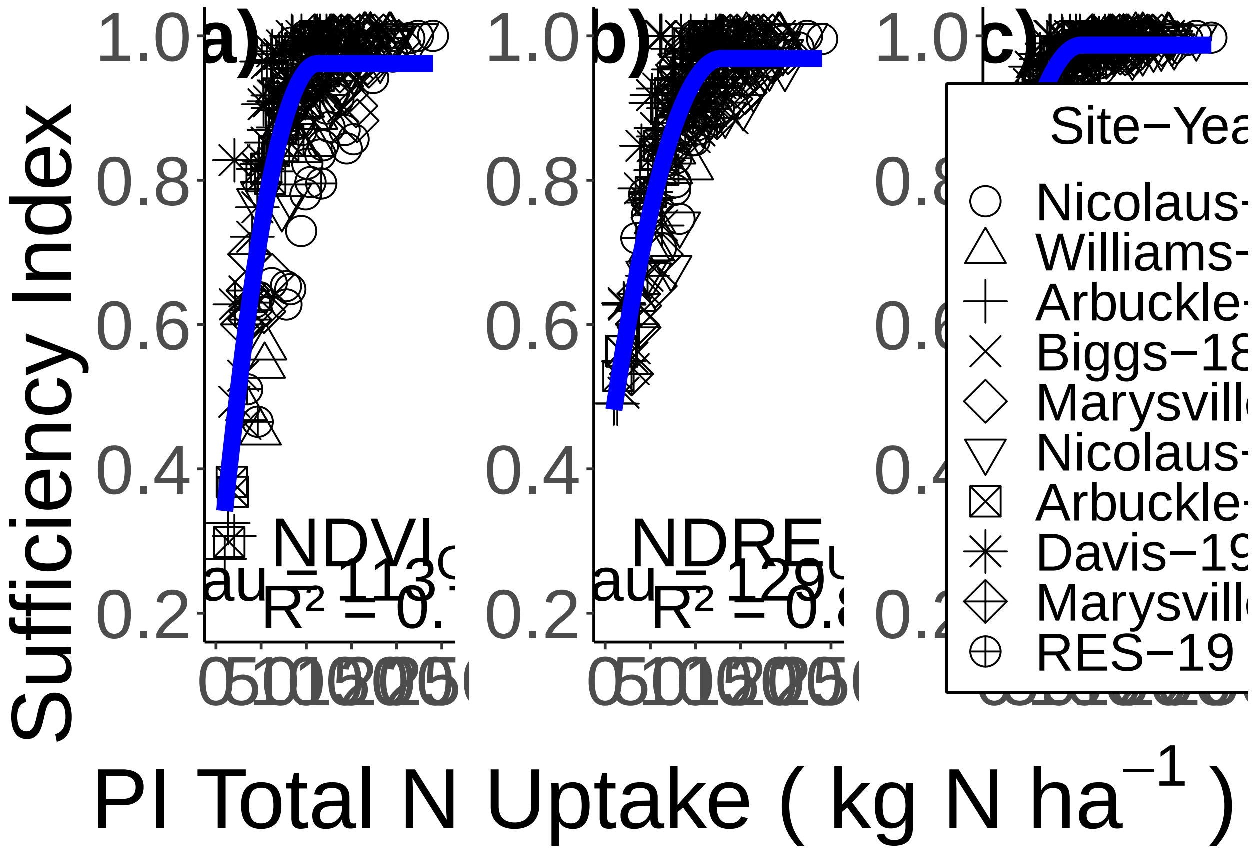


FIGURE 4

```
Fig4 <- grid.arrange(arrangeGrob(GS_ndvi_si_quad_plot,
                                 suas_ndre_si_quad_plot,
                                 suas_ndvi_si_quad_plot,
                                 left = textGrob("Sufficiency Index" , rot = 90 , gp = gpar(fo
                          bottom = textGrob("PI Total N Uptake ( kg N ha"^-1~")" , gp = gpar(fo
                          nrow = 1,
                          ncol = 3
                          ))
```




```
ggsave("FIGURES/Fig4.tiff" , Fig4 , compression = "lzw" , width = 22 , height = 10, type = "cairo" , dp
```

FIGURE 5

gs ndvi SI

```
ctrl <- lmeControl(opt = "optim") #changes control to "optimal" settings



gsndvi_yield_mixlm <- lme(fixed = GrainYield_Mgha ~ SI ,
                          random = ~I(SI) | site_year,
                          data = paper3_gsdata)

summary(gsndvi_yield_mixlm)
```

model

```
## Linear mixed-effects model fit by REML
##   Data: paper3_gsdata
##        AIC      BIC    logLik
##   632.2034 652.9609 -310.1017
##
## Random effects:
##  Formula: ~I(SI) | site_year
##  Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev    Corr
```

```
## (Intercept) 2.8528028 (Intr)
## I(SI)       3.2215774 -0.936
## Residual    0.7974361
##
## Fixed effects:  GrainYield_Mgha ~ SI
##                 Value Std.Error  DF  t-value p-value
## (Intercept) 1.756200 0.9680527 226 1.814157   0.071
## SI          9.547127 1.0902077 226 8.757164   0.000
##  Correlation:
##    (Intr)
## SI -0.943
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -3.34438501 -0.54121956  0.01143244  0.58140764  2.20039027
##
## Number of Observations: 237
## Number of Groups: 10
```

```
summary(gsndvi_yield_mixlm)$tTable
```

```
##                 Value Std.Error  DF  t-value      p-value
## (Intercept) 1.756200 0.9680527 226 1.814157 7.097962e-02
## SI          9.547127 1.0902077 226 8.757164 4.774230e-16
```

```
Anova(gsndvi_yield_mixlm , type = 2)
```

```
## Analysis of Deviance Table (Type II tests)
##
## Response: GrainYield_Mgha
##     Chisq Df Pr(>Chisq)
## SI 76.688  1  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Anova(gsndvi_yield_mixlm , type = 3)
```

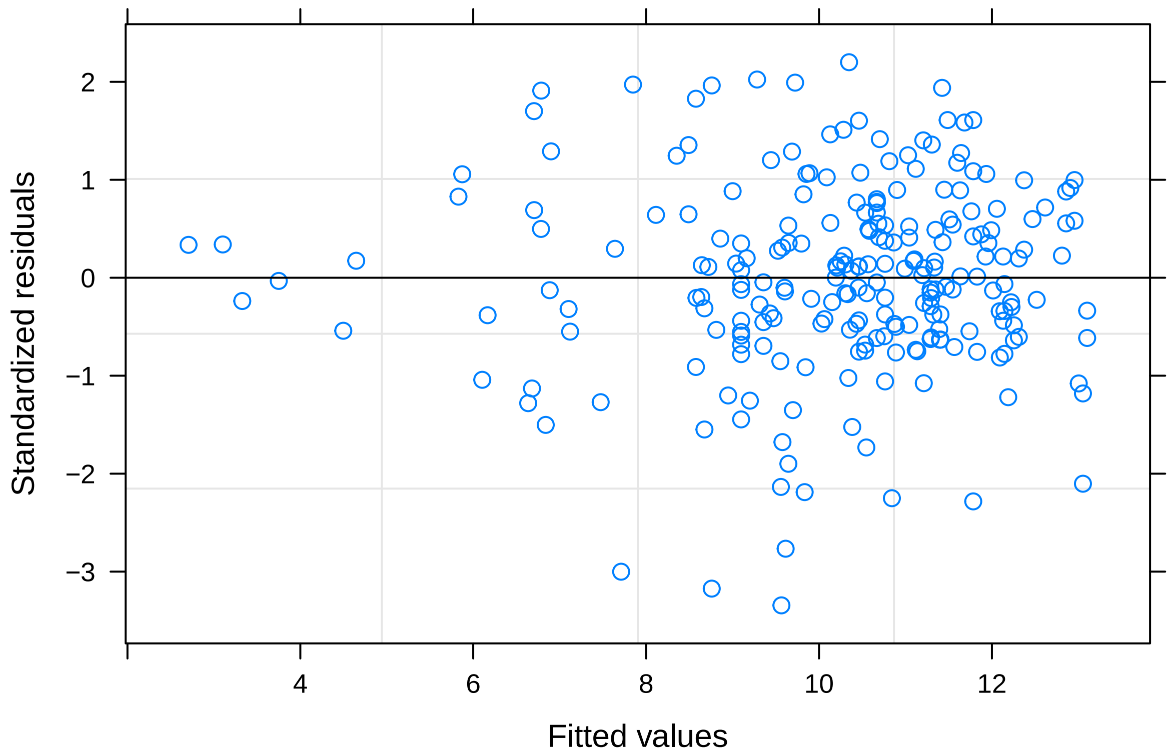
```
## Analysis of Deviance Table (Type III tests)
##
## Response: GrainYield_Mgha
##               Chisq Df Pr(>Chisq)
## (Intercept)  3.2912  1    0.06965 .
## SI          76.6879  1    < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
r.squaredGLMM(gsndvi_yield_mixlm)
```

```
## Warning: 'r.squaredGLMM' now calculates a revised statistic. See the help page.
```

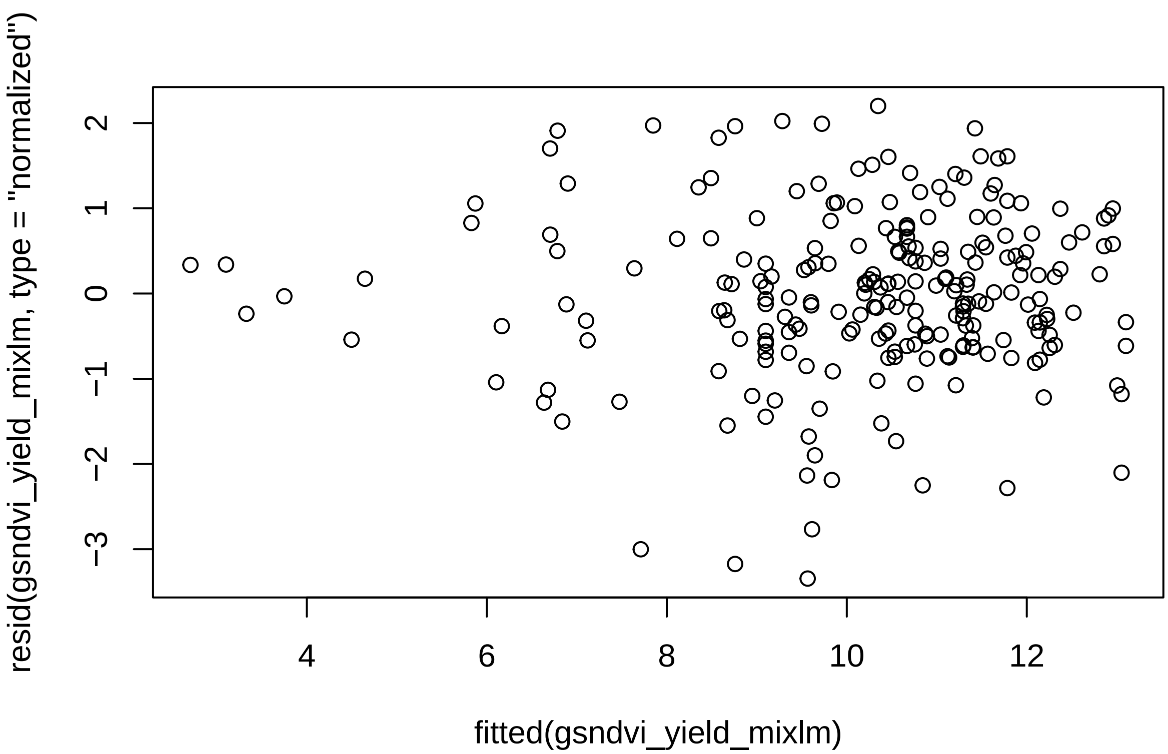
```
##            R2m       R2c
## [1,] 0.5345773 0.8466198
```

```
plot (gsndvi_yield_mixlm)
```



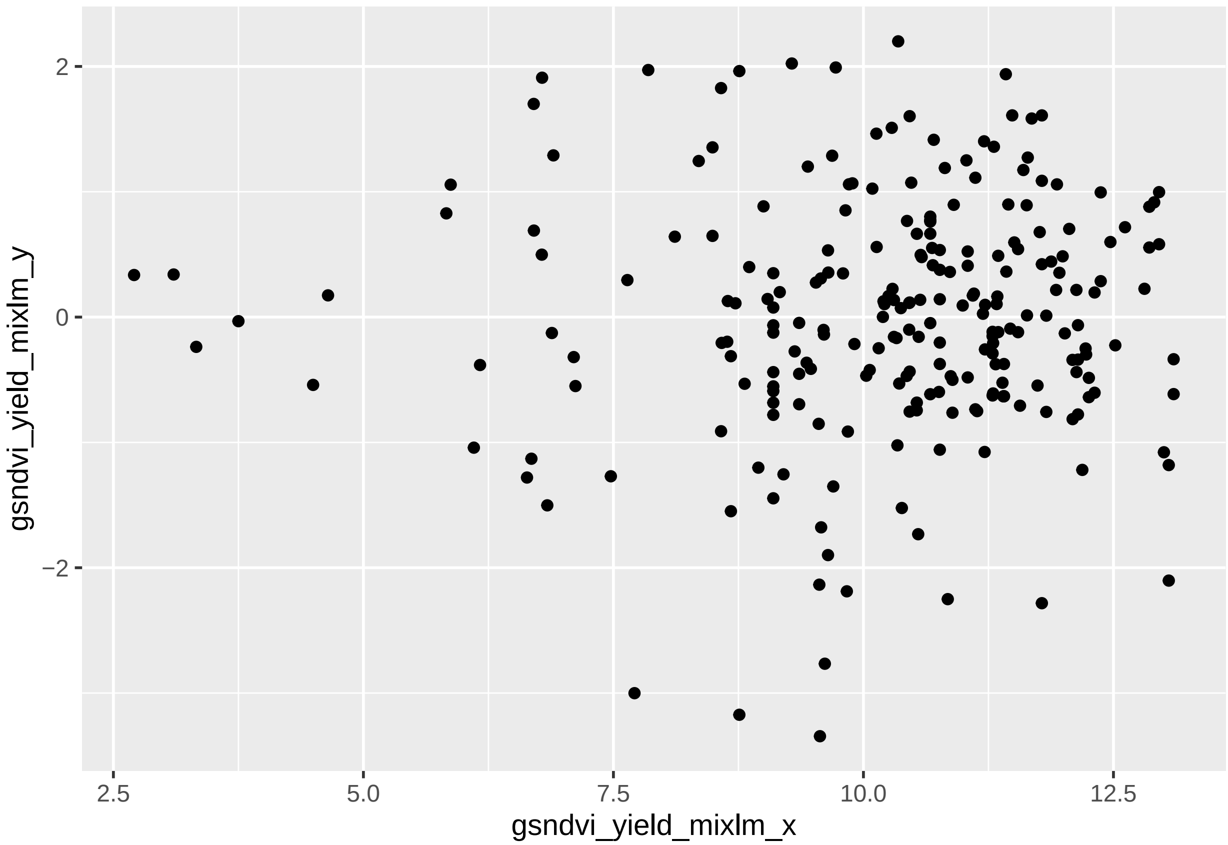
diagnostics

```
plot(resid(gsndvi_yield_mixlm, type = "normalized") ~fitted(gsndvi_yield_mixlm))
```

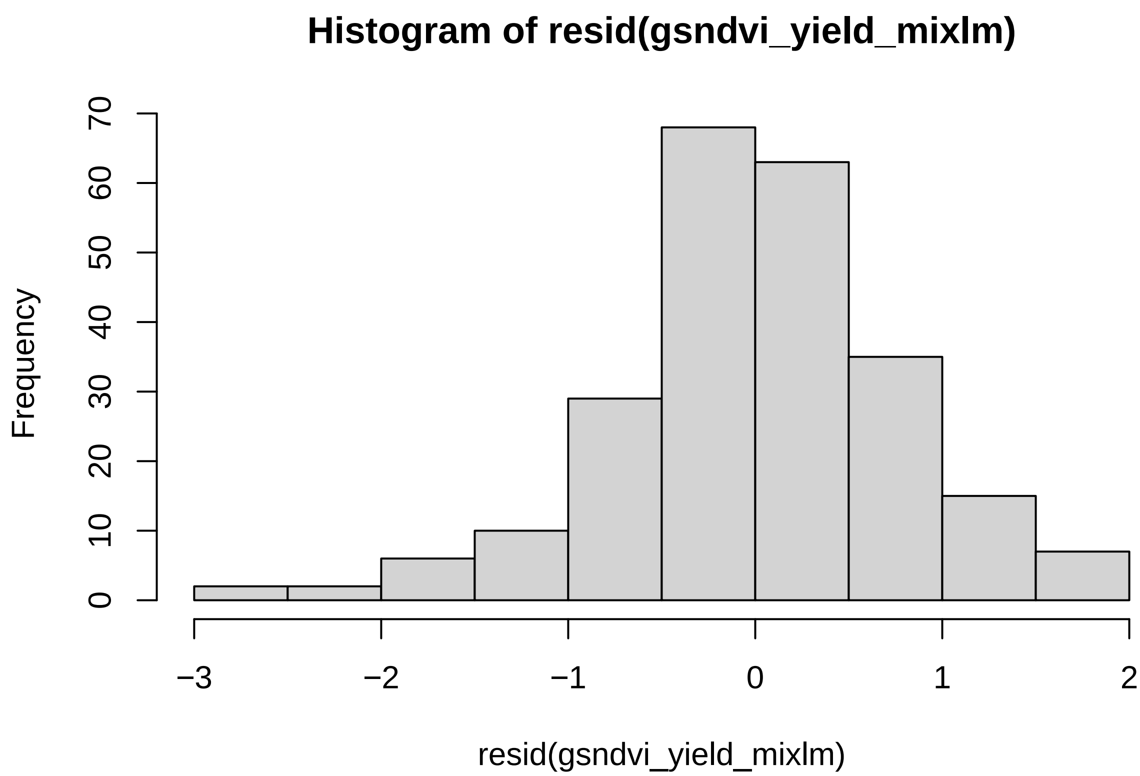



```
gsndvi_yield_mixlm_y <- resid(gsndvi_yield_mixlm, type = "normalized")
gsndvi_yield_mixlm_x <- fitted(gsndvi_yield_mixlm)

gsndvi_yield_mixlmresid_data <- data.frame(gsndvi_yield_mixlm_x , gsndvi_yield_mixlm_y)
```

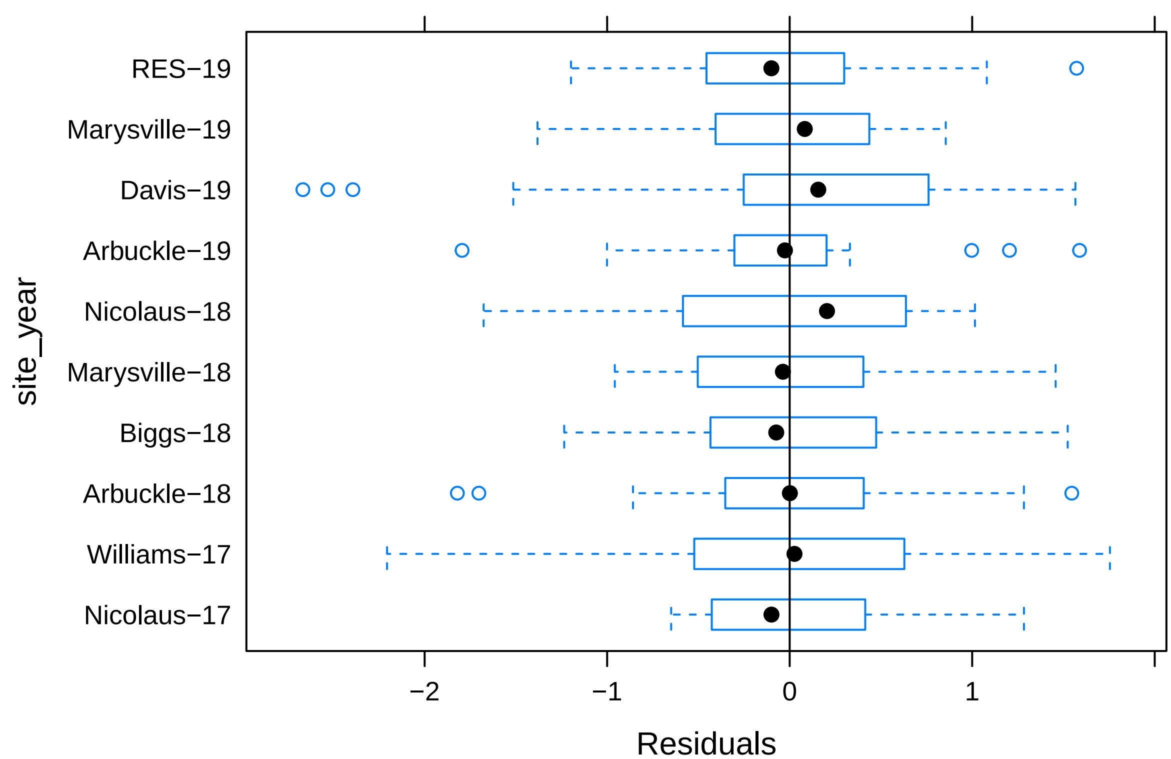
```
ggplot( data = gsndvi_yield_mixlmresid_data , aes( x = gsndvi_yield_mixlm_x , y = gsndvi_yield_mixlm_y))
  geom_point(mapping = aes(gsndvi_yield_mixlm_x , gsndvi_yield_mixlm_y) , data = gsndvi_yield_mixlmresi
```



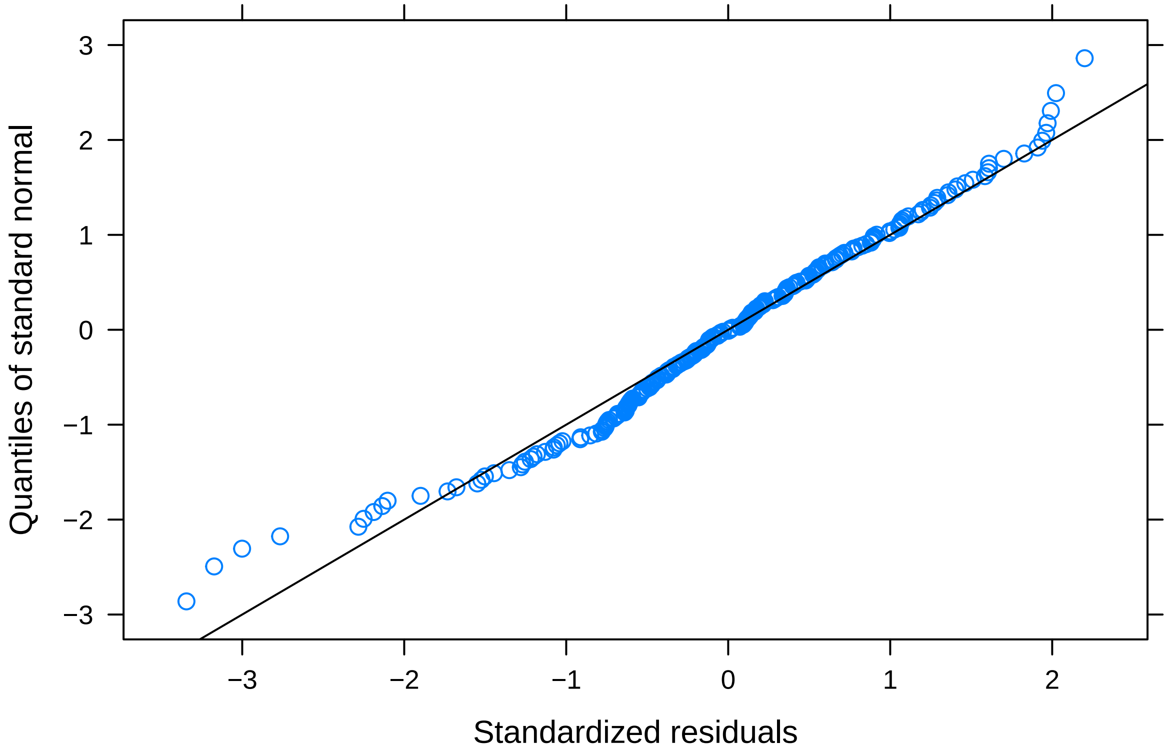

```
hist(resid(gsndvi_yield_mixlm))
```



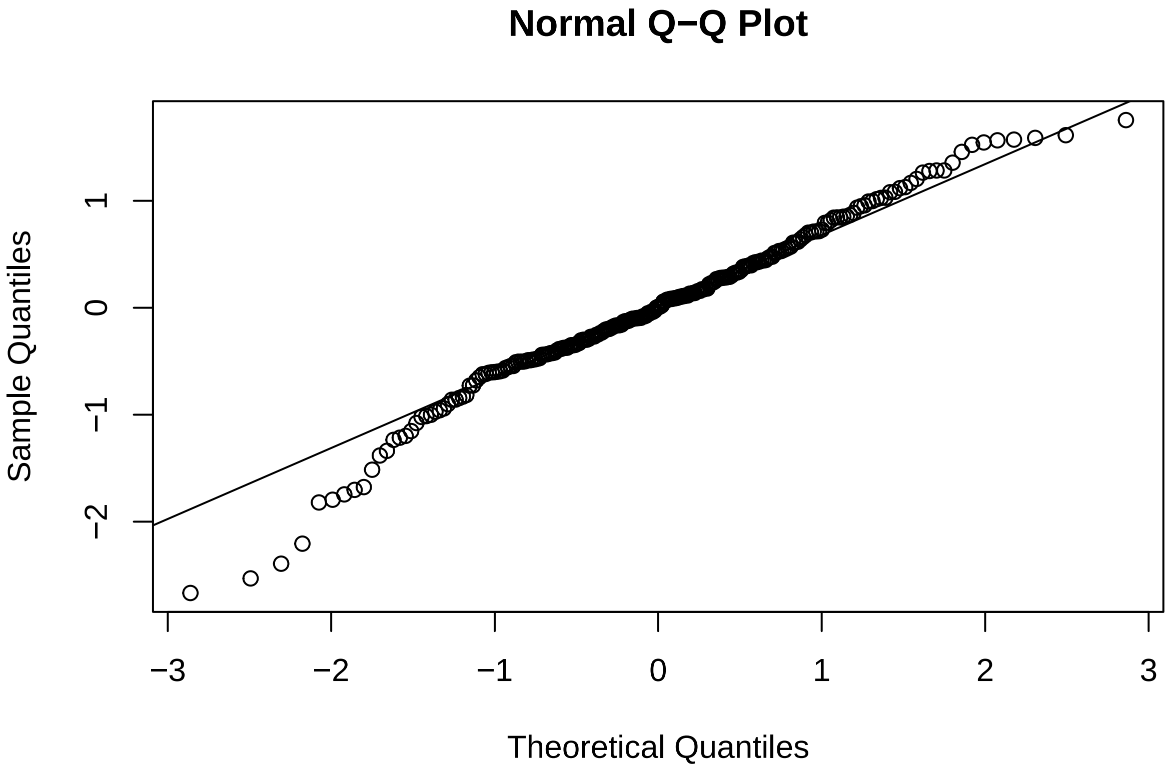

```
plot(gsndvi_yield_mixlm, site_year ~ resid(.), abline = 0)
```



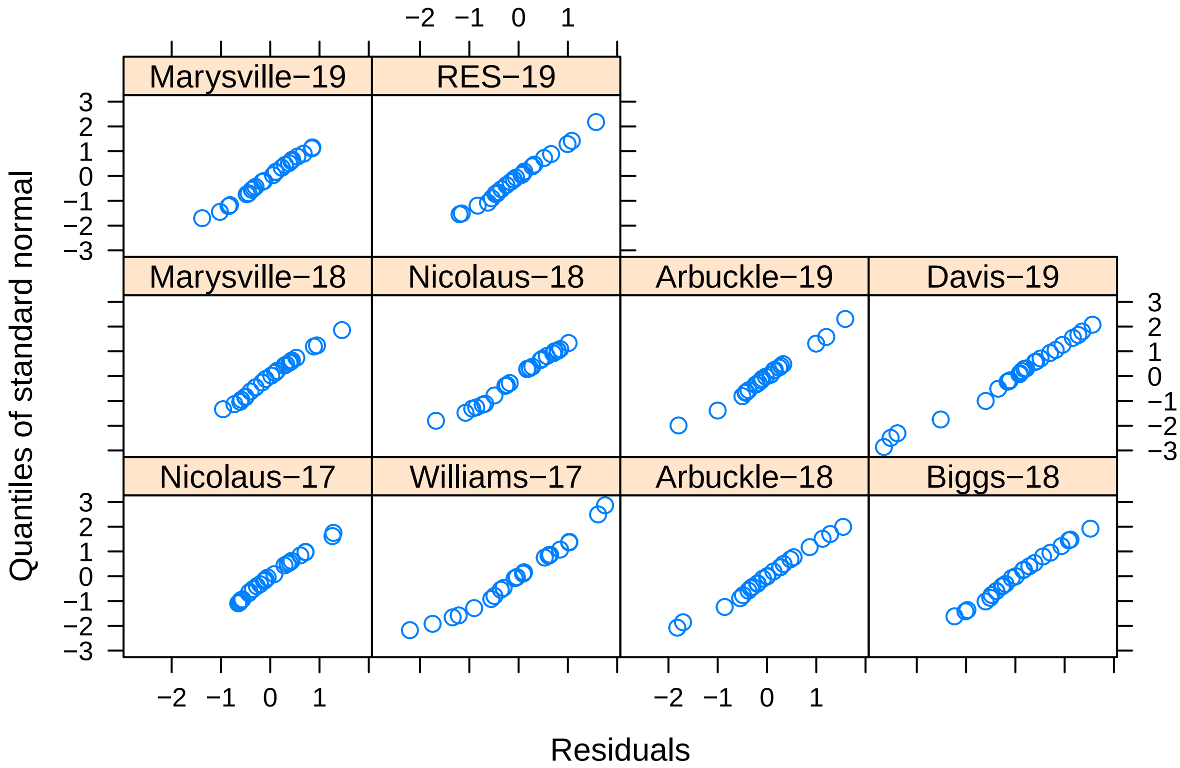

```
qqnorm(gsndvi_yield_mixlm, abline = c(0,1) )
```



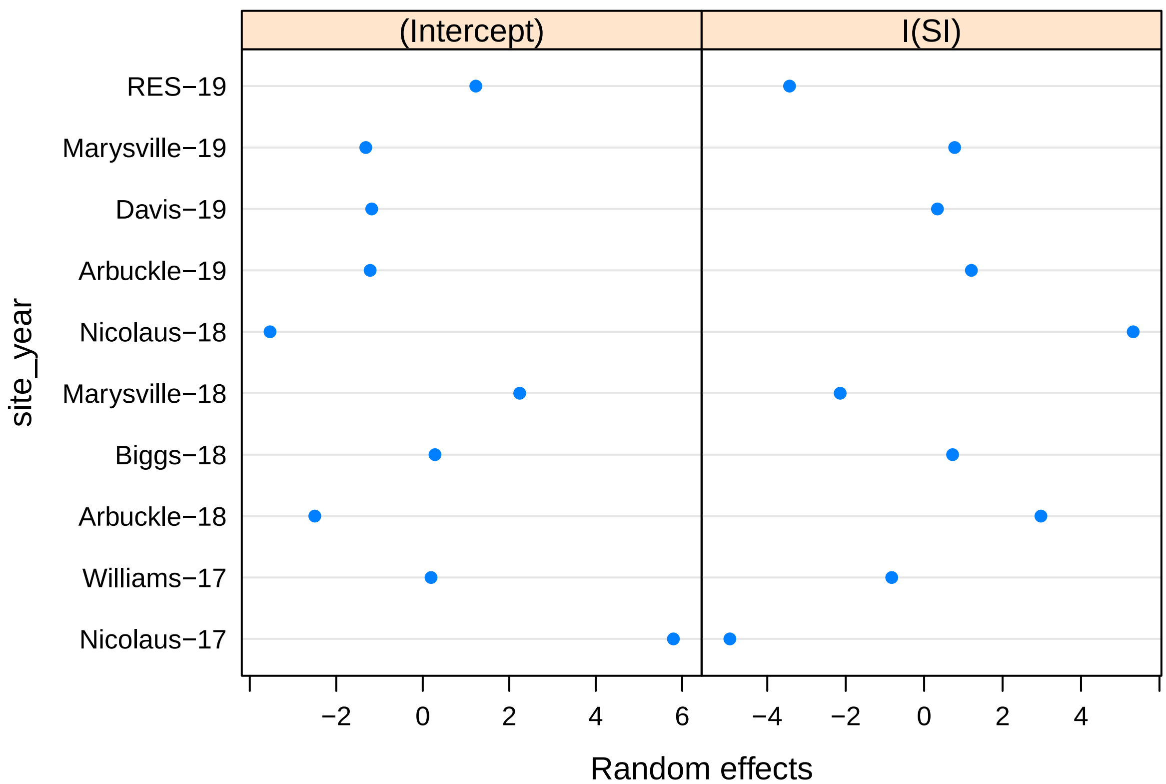

```
qqnorm(resid(gsndvi_yield_mixlm))
qqline(resid(gsndvi_yield_mixlm))
```



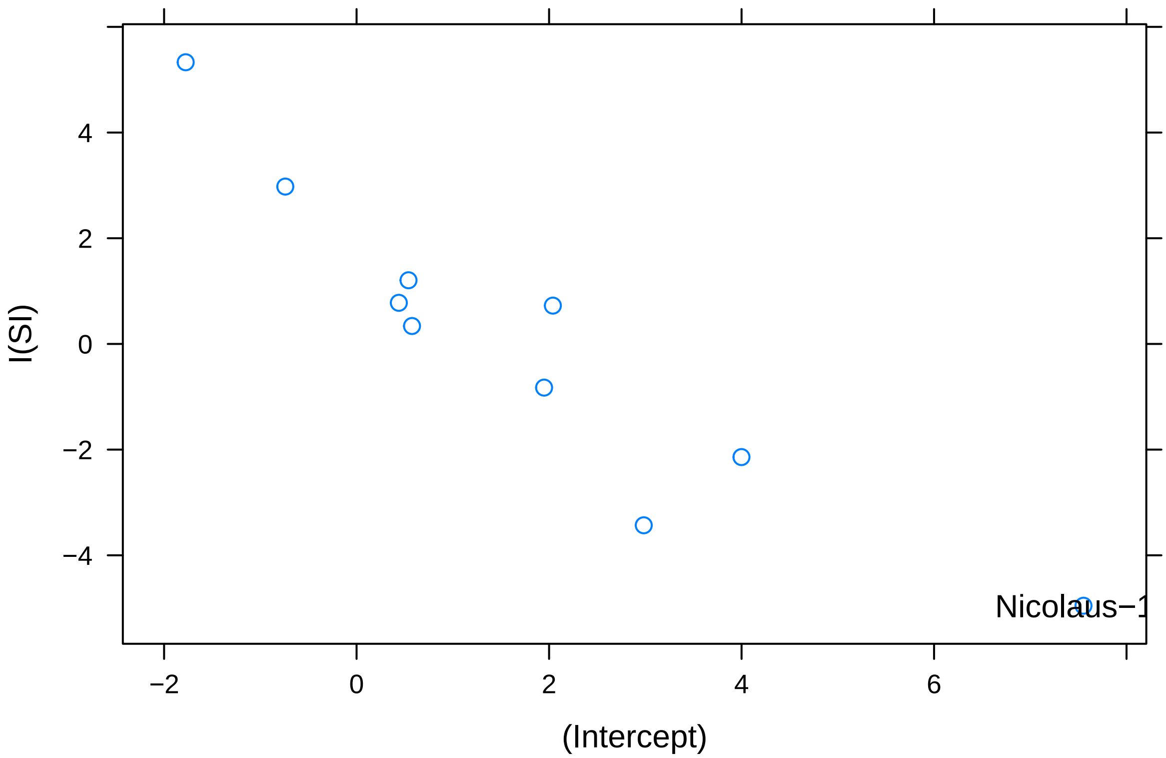

```
qqnorm(gsndvi_yield_mixlm , ~resid(.) | site_year)
```



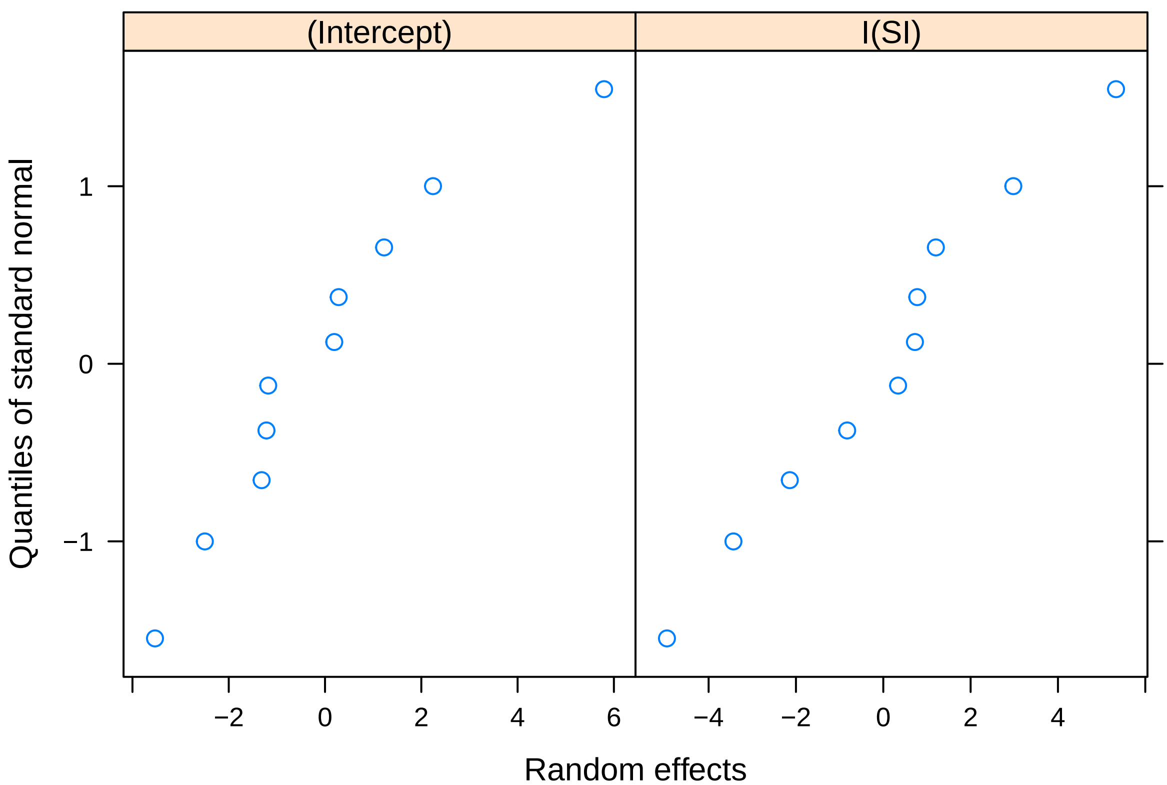

```
plot(ranef(gsndvi_yield_mixlm))
```



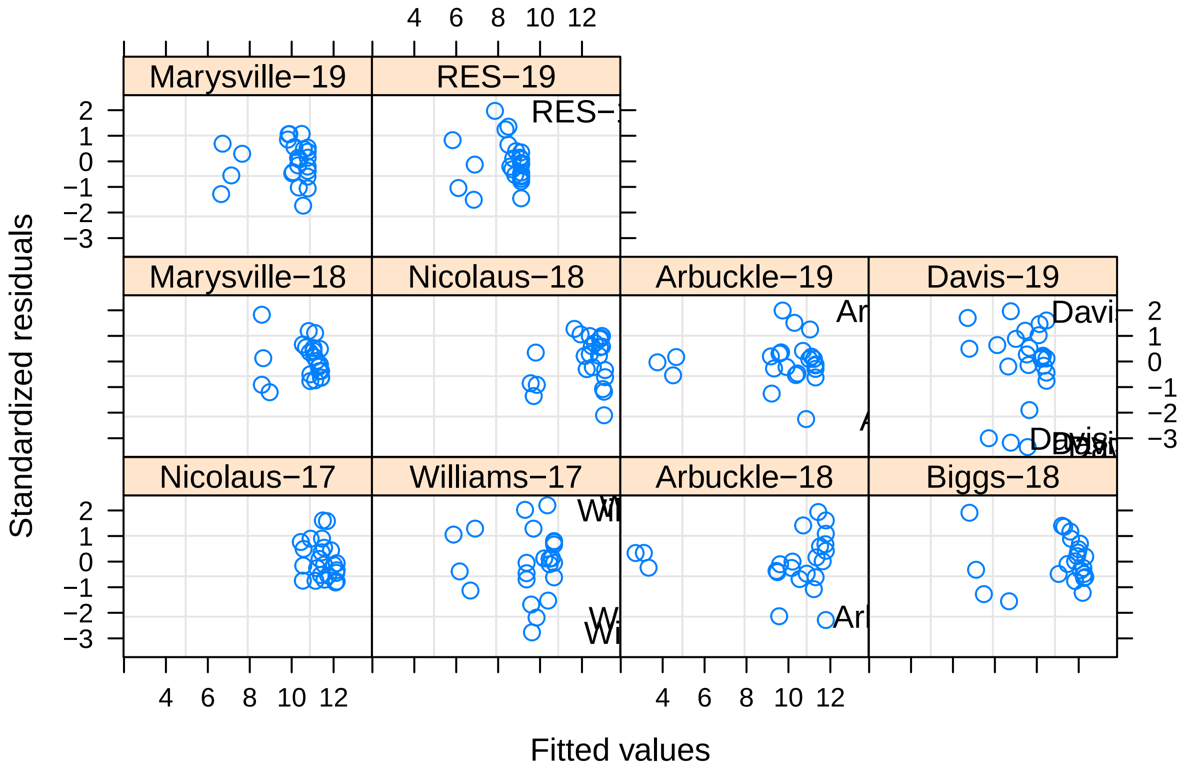

```
pairs(gsndvi_yield_mixlm , id = 0.1)
```




```
qqnorm(gsndvi_yield_mixlm , ~ranef(.))
```



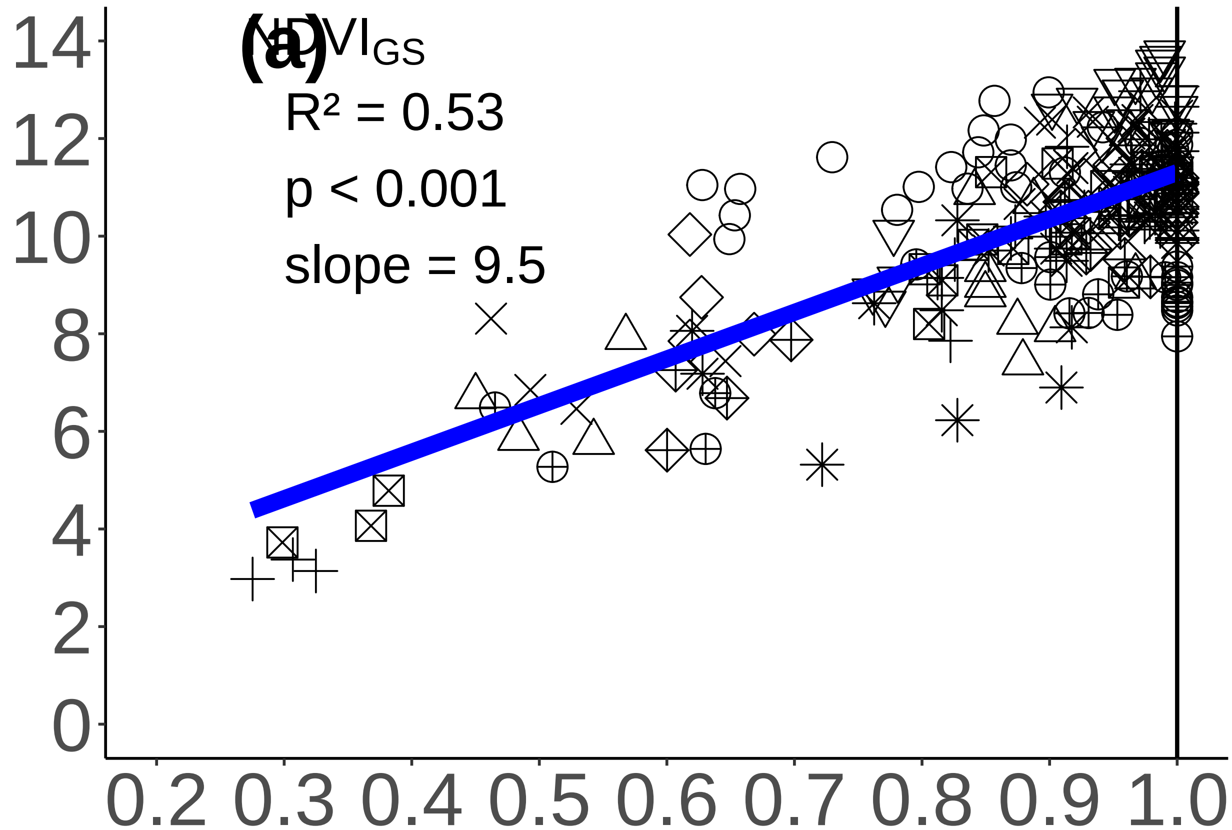

```
plot( gsndvi_yield_mixlm, resid(., type = "p") ~ fitted(.) | site_year,
      id = 0.05, adj = -0.3 )
```




```
mylist <- list(SI=seq(round(min(paper3_gsdata$SI), digits = 3) , 1 , by = .001))

gsndvi_emmeans <- as.data.frame(summary(emmeans(gsndvi_yield_mixlm , ~ SI , at = mylist )))
```

emmeans

```
plot_si1 <- ggplot( data = paper3_gsdata , aes( x = SI , y = GrainYield_Mgha)) +
  geom_point( data = paper3_gsdata , aes( x = SI , y = GrainYield_Mgha , shape = site_year) , size = 5)
  geom_line( data = gsndvi_emmeans , aes(x = SI , y = emmean) , color = "blue" , size = 3) +
  theme_classic() +
  labs( x = NULL , y = NULL , color = "Index") +
  scale_x_continuous(breaks = seq(.2 , 1 , by = .1)) +
  scale_y_continuous(breaks = seq(0 , 14 , by = 2)) +
  coord_cartesian(ylim = c(0,14) , xlim = c(.2 , 1)) +
  geom_vline(xintercept = 1 , size = 0.75) +
  theme(axis.text = element_text(size = 28),
        axis.title = element_text(size = 28),
        legend.text = element_text(size = 24),
        legend.title = element_text(size = 24),
        legend.position = "none") +
  annotate("text", x=0.3, y=11, label="R² = 0.53\np < 0.001\nslope = 9.5", size = 7 , color = "black" ,
  annotate("text", x=0.3, y=14, label="(a)", size = 10 , color = "black" , hjust = 0.5 , fontface = 2)
  annotate("text", x=0.34, y=14, label="NDVI[GS]", size = 7 , color = "black" , hjust = 0.5 , parse = T
  scale_shape_manual(values = c(1:20))

plot_si1
```



plot

sUAS ndvi RI

```
sUASndvi_yield_mixlm <- lme(fixed = GrainYield_Mgha ~ SI ,
                           random = ~I(SI) | site_year,
                           data = paper3_uas_ndvi_data)

summary(sUASndvi_yield_mixlm)
```

model

```
## Linear mixed-effects model fit by REML
##   Data: paper3_uas_ndvi_data
##        AIC      BIC    logLik
##   639.7817 660.5392 -313.8908
##
## Random effects:
##  Formula: ~I(SI) | site_year
##  Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev    Corr
## (Intercept) 7.6291818 (Intr)
## I(SI)       8.0549586 -0.99
## Residual    0.8161178
##
## Fixed effects:  GrainYield_Mgha ~ SI
##                  Value Std.Error  DF   t-value p-value
## (Intercept) -14.12294  2.643468 226 -5.342579       0
## SI           25.33529  2.781592 226  9.108198       0
```

```
##  Correlation:
##    (Intr)
## SI -0.992
##
## Standardized Within-Group Residuals:
##         Min          Q1         Med          Q3         Max
## -5.15225909 -0.55392647  0.05855843  0.56664149  2.24710746
##
## Number of Observations: 237
## Number of Groups: 10
```

```
summary(sUASndvi_yield_mixlm)$tTable
```

```
##                 Value Std.Error  DF   t-value      p-value
## (Intercept) -14.12294  2.643468 226 -5.342579 2.232467e-07
## SI           25.33529  2.781592 226  9.108198 4.573975e-17
```

```
Anova(sUASndvi_yield_mixlm , type = 2)
```

```
## Analysis of Deviance Table (Type II tests)
##
## Response: GrainYield_Mgha
##     Chisq Df Pr(>Chisq)
## SI 82.959  1  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

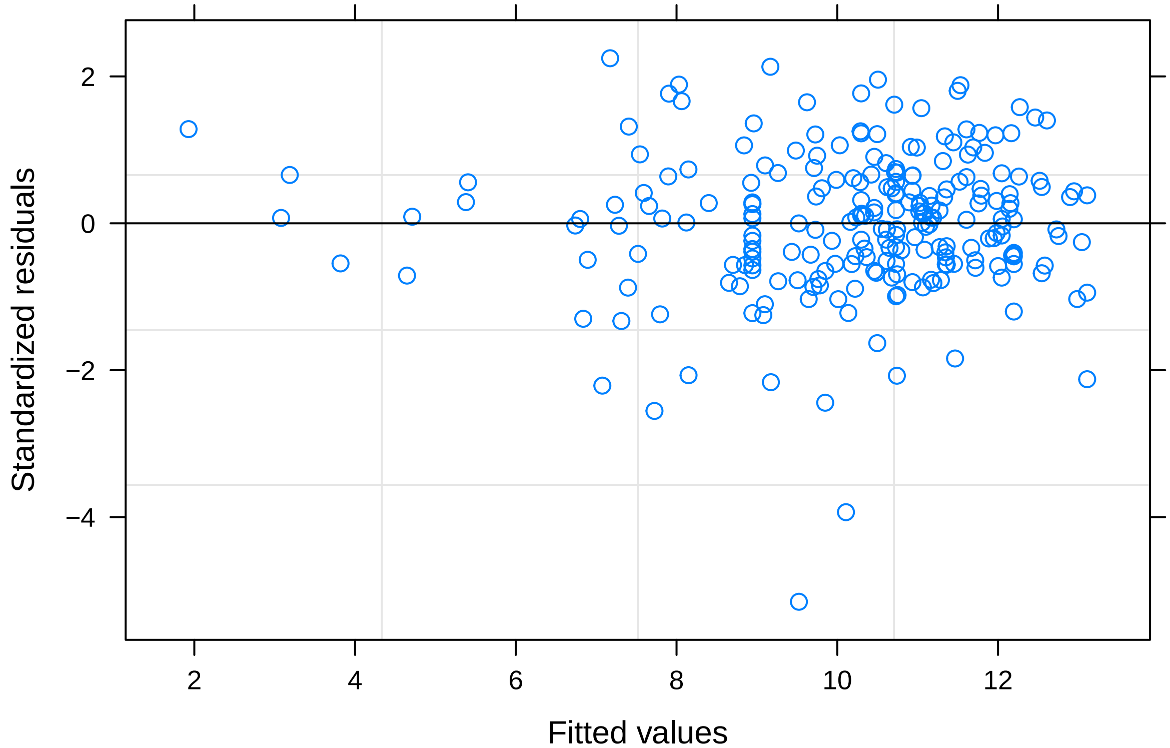
```
Anova(sUASndvi_yield_mixlm , type = 3)
```

```
## Analysis of Deviance Table (Type III tests)
##
## Response: GrainYield_Mgha
##              Chisq Df Pr(>Chisq)
## (Intercept) 28.543  1  9.163e-08 ***
## SI          82.959  1  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
r.squaredGLMM(sUASndvi_yield_mixlm)
```

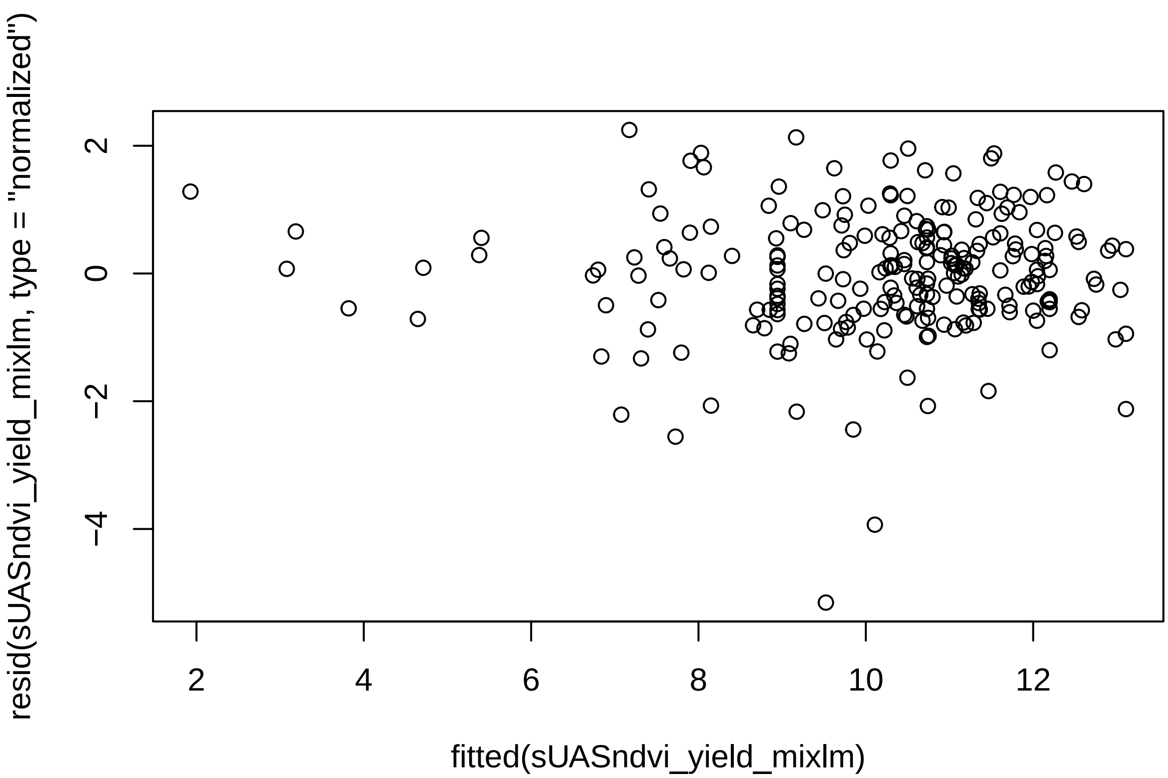
```
##            R2m       R2c
## [1,] 0.5352913 0.8488972
```

```

plot (sUASndvi_yield_mixlm)
```



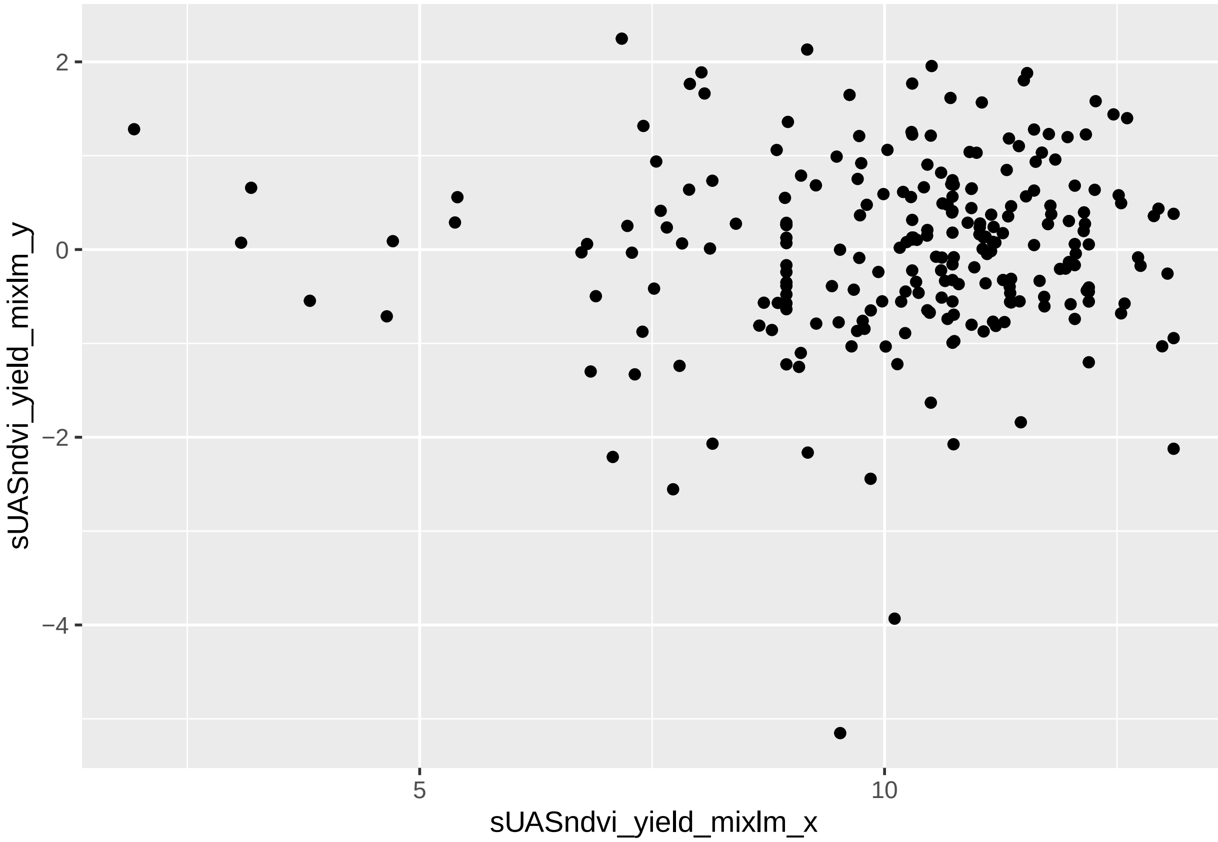
diagnostics

```
plot(resid(sUASndvi_yield_mixlm, type = "normalized") ~fitted(sUASndvi_yield_mixlm))
```

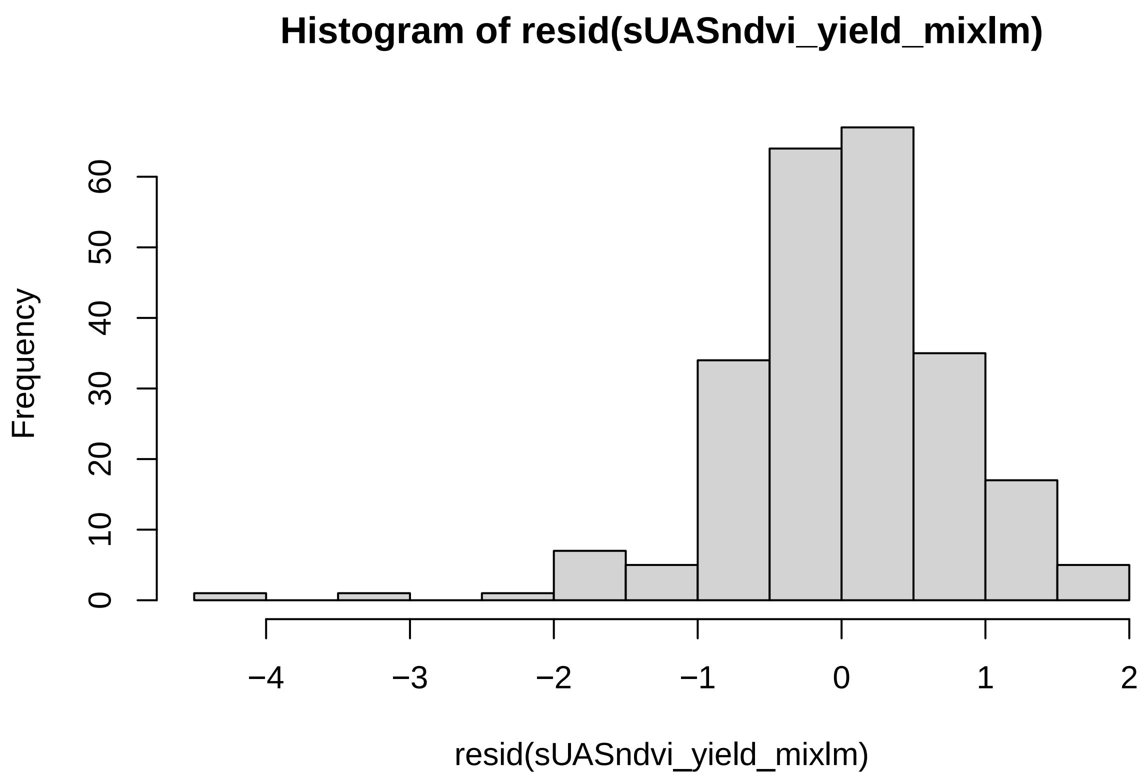



```
sUASndvi_yield_mixlm_y <- resid(sUASndvi_yield_mixlm, type = "normalized")
sUASndvi_yield_mixlm_x <- fitted(sUASndvi_yield_mixlm)
```

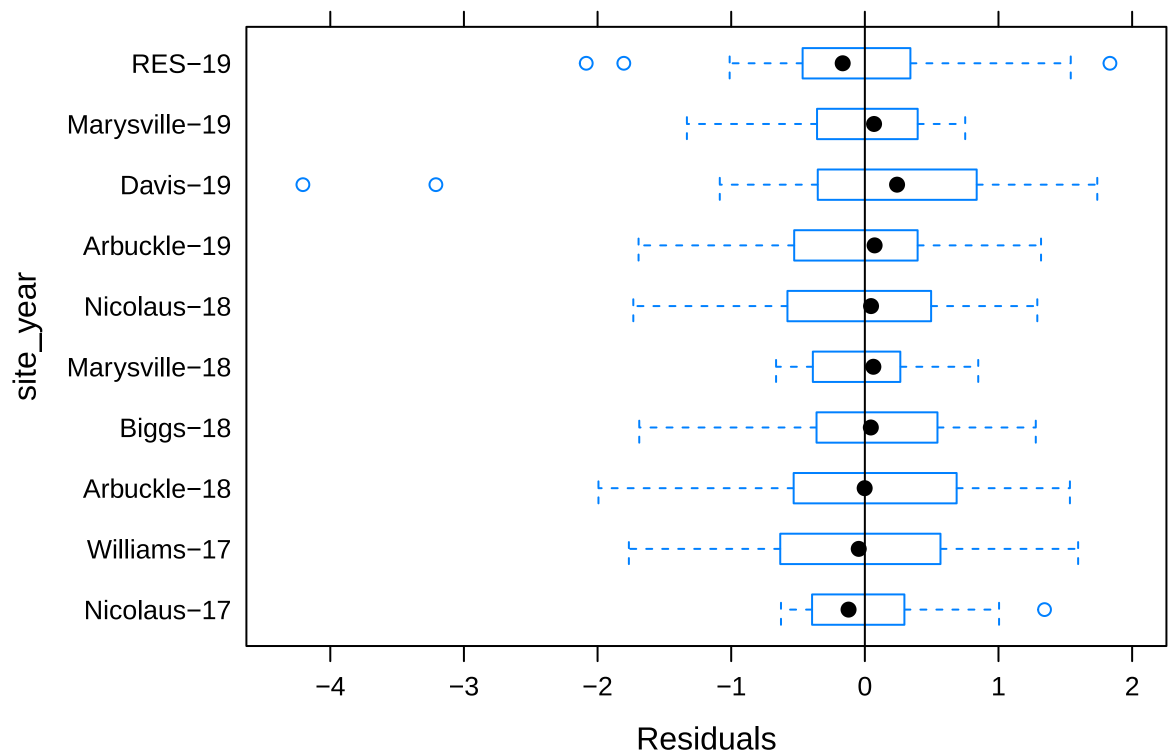
```r
sUASndvi_yield_mixlmresid_data <- data.frame(sUASndvi_yield_mixlm_x , sUASndvi_yield_mixlm_y)

ggplot( data = sUASndvi_yield_mixlmresid_data , aes( x = sUASndvi_yield_mixlm_x , y = sUASndvi_yield_mi
  geom_point(mapping = aes(sUASndvi_yield_mixlm_x , sUASndvi_yield_mixlm_y) , data = sUASndvi_yield_mixl
```



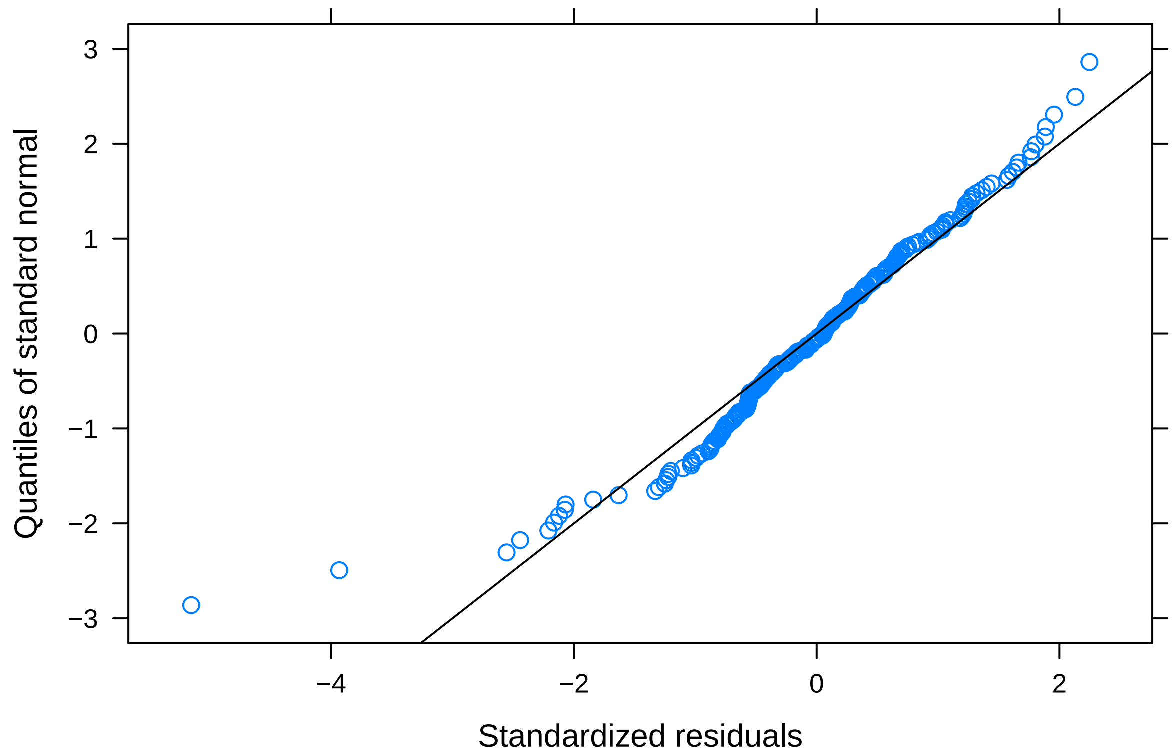

```r
hist(resid(sUASndvi_yield_mixlm))
```



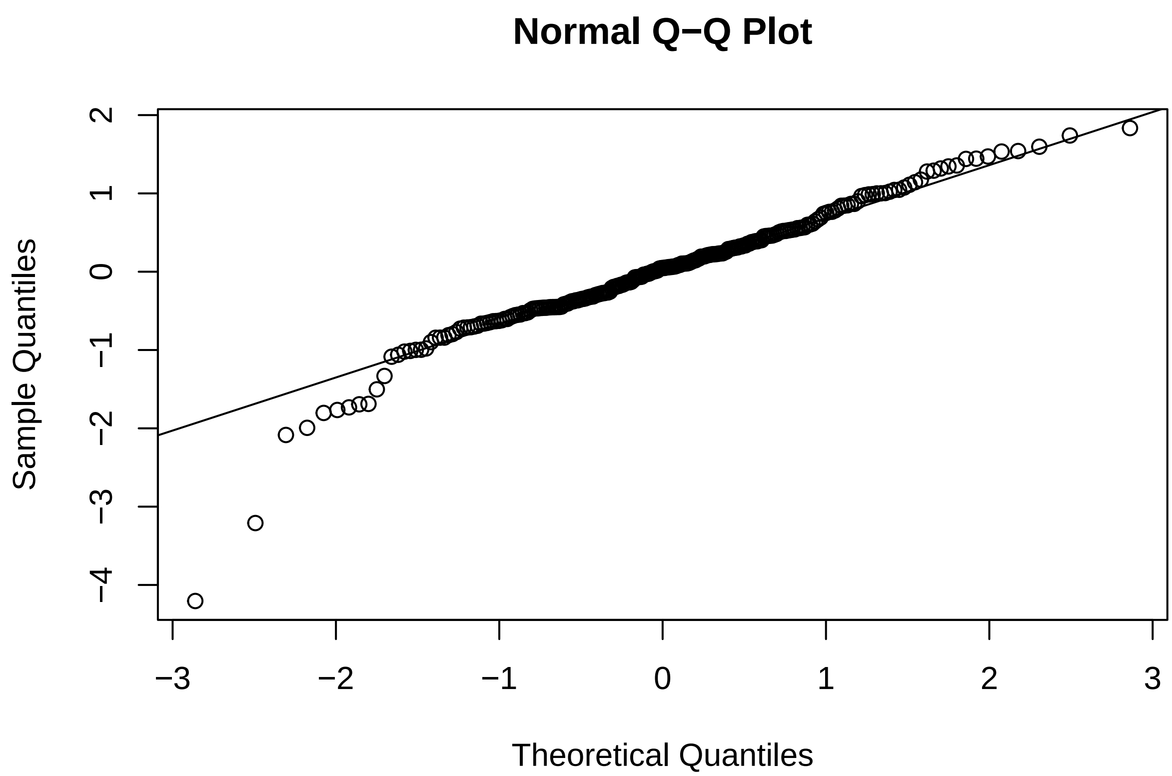

```
plot(sUASndvi_yield_mixlm, site_year ~ resid(.), abline = 0)
```



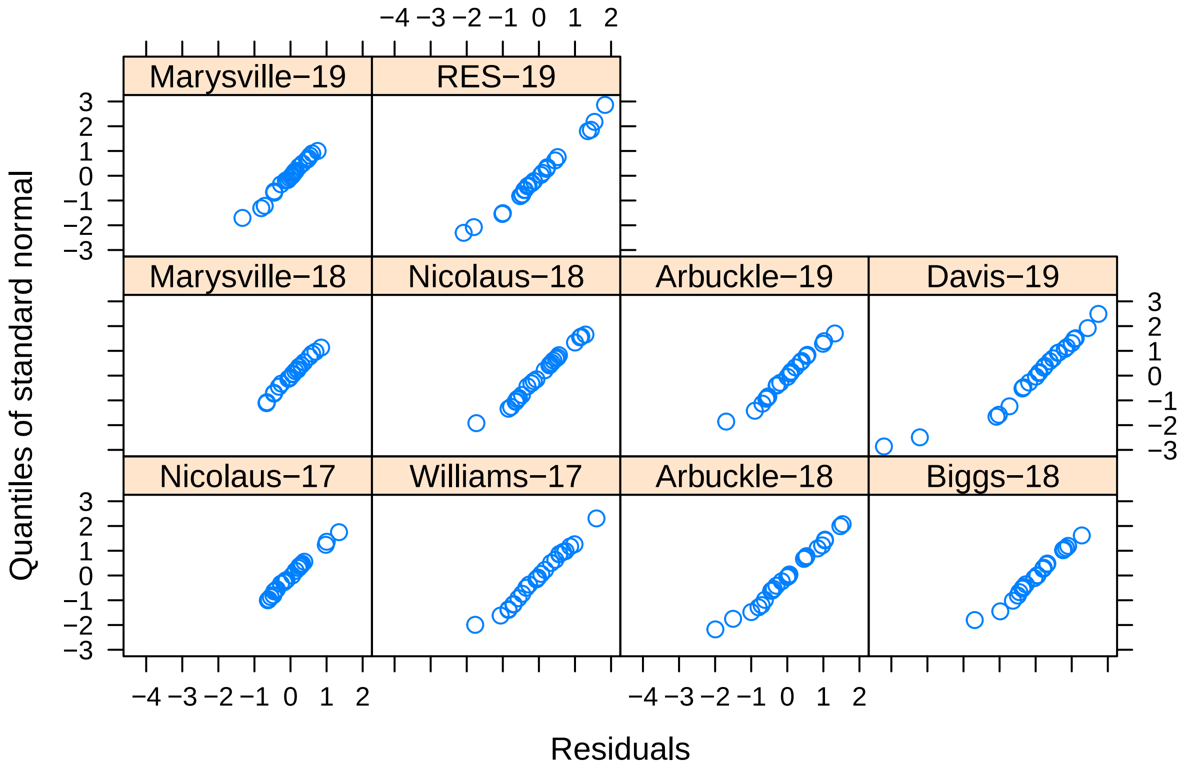

```
qqnorm(sUASndvi_yield_mixlm, abline = c(0,1) )
```



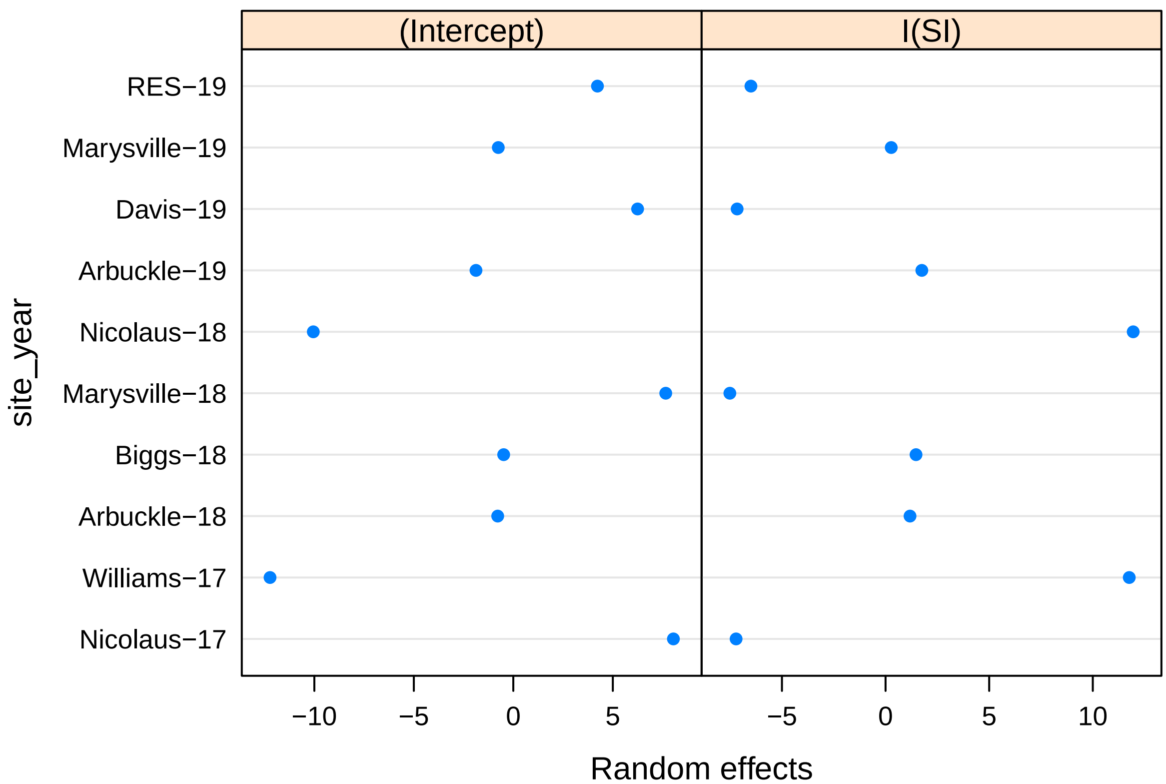

```
qqnorm(resid(sUASndvi_yield_mixlm))
qqline(resid(sUASndvi_yield_mixlm))
```



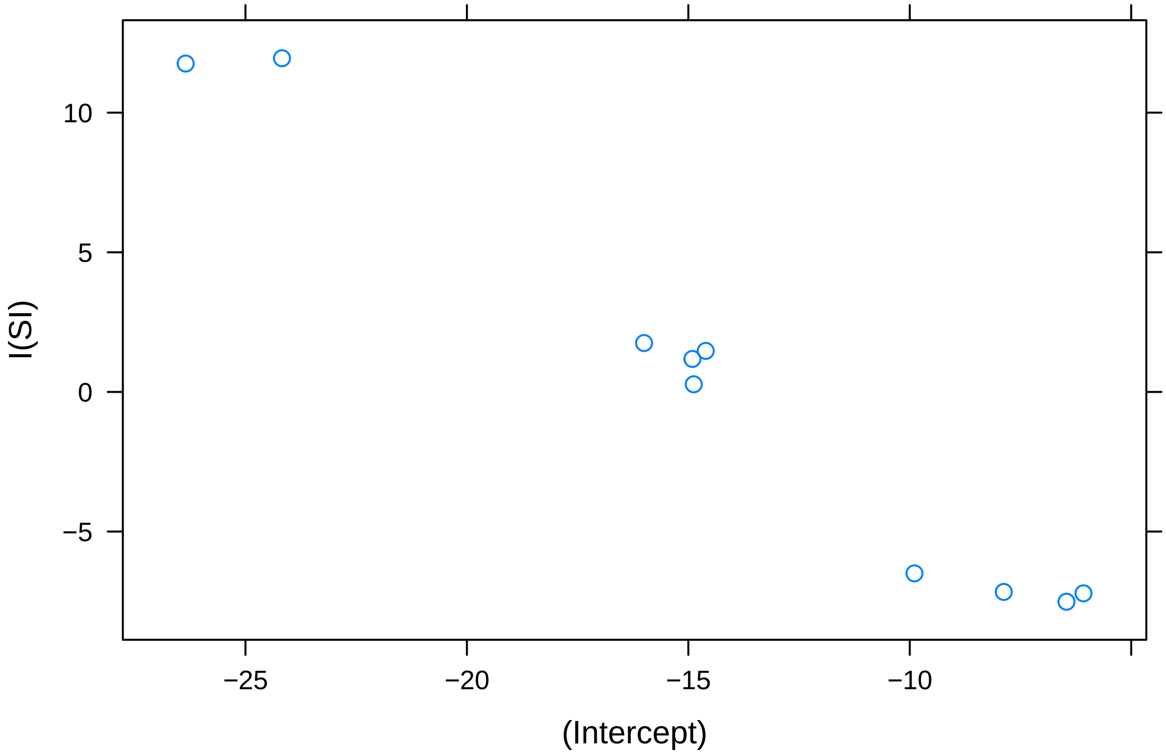

```
qqnorm(sUASndvi_yield_mixlm , ~resid(.) | site_year)
```



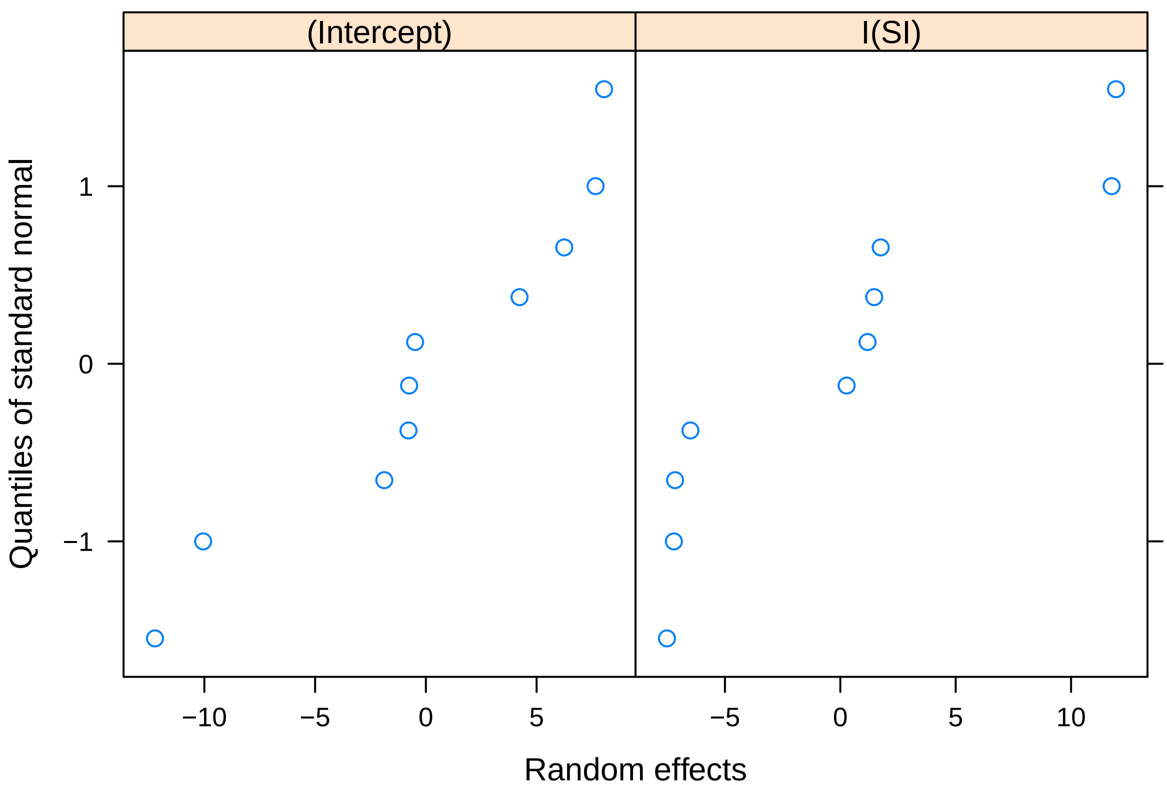

```
plot(ranef(sUASndvi_yield_mixlm))
```



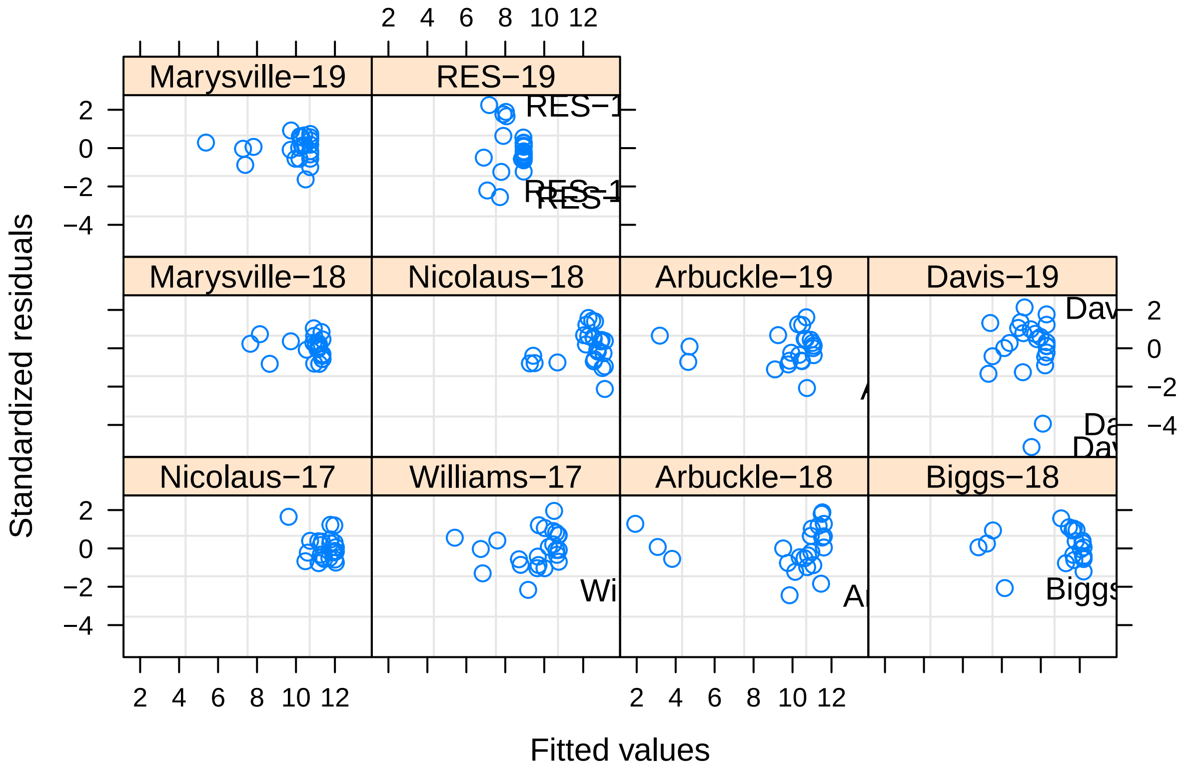

```
pairs(sUASndvi_yield_mixlm , id = 0.1)
```




```
qqnorm(sUASndvi_yield_mixlm , ~ranef(.))
```



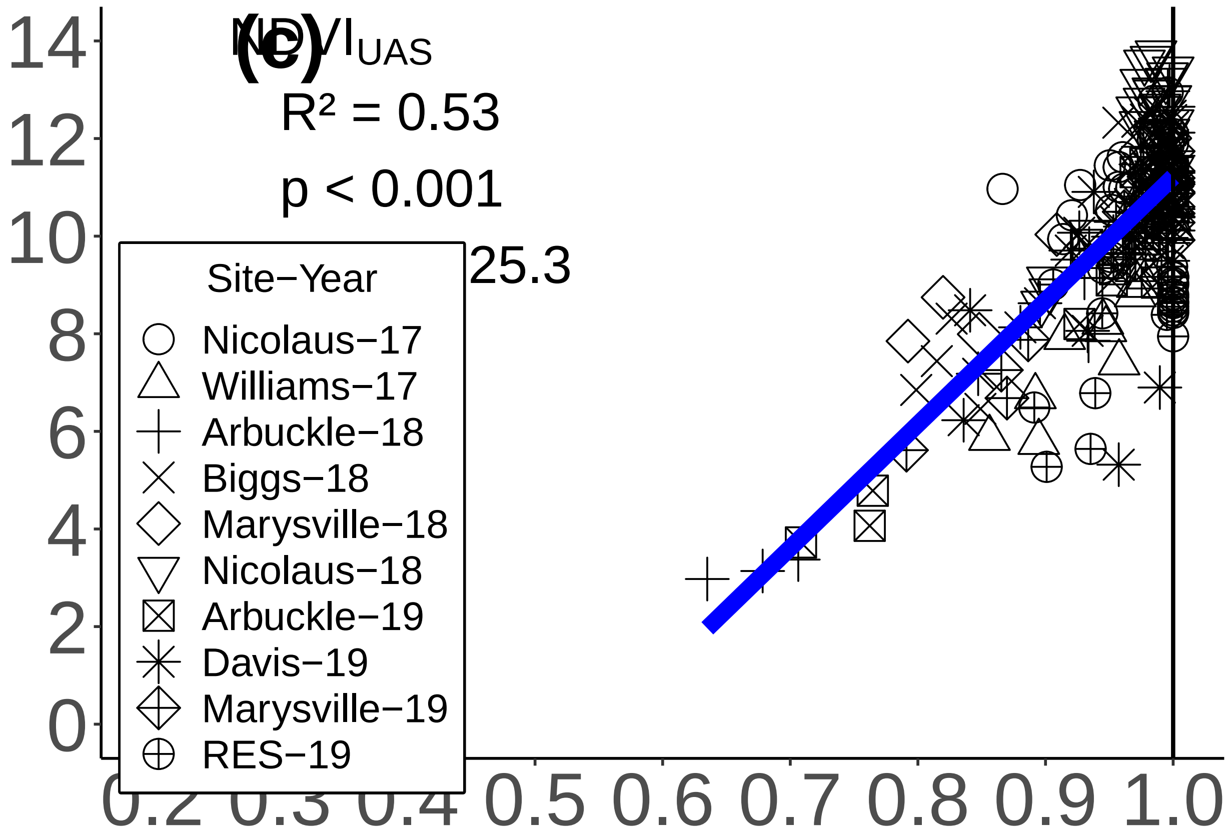

```
plot( sUASndvi_yield_mixlm, resid(., type = "p") ~ fitted(.) | site_year,
      id = 0.05, adj = -0.3 )
```




```
mylist <- list(SI=seq(round(min(paper3_uas_ndvi_data$SI), digits = 3) , 1 , by = .001))

sUASndvi_emmeans <- as.data.frame(summary(emmeans(sUASndvi_yield_mixlm , ~ SI , at = mylist )))
```

emmeans

```
plot_si2 <- ggplot( data = paper3_uas_ndvi_data , aes( x = SI , y = GrainYield_Mgha)) +
  geom_point( data = paper3_uas_ndvi_data , aes( x = SI , y = GrainYield_Mgha , shape = site_year) , si
  geom_line( data = sUASndvi_emmeans , aes(x = SI , y = emmean) , color = "blue" , size = 3) +
  theme_classic() +
  labs( x = NULL , y = NULL , shape = "Site-Year") +
  scale_x_continuous(breaks = seq(0.2 , 1 , by = .1)) +
  scale_y_continuous(breaks = seq(0 , 14 , by = 2)) +
  coord_cartesian(ylim = c(0,14) , xlim = c(0.2 , 1)) +
  geom_vline(xintercept = 1 , size = 0.75) +
  theme(axis.text = element_text(size = 28),
        axis.title = element_text(size = 28),
        legend.text = element_text(size = 15),
        legend.title = element_text(size = 15 , hjust = 0.5),
        legend.position = c(.17 , .32),
        legend.box.background = element_rect(size = 1)) +
  annotate("text", x=0.3, y=11, label="R² = 0.53\np < 0.001\nslope = 25.3", size=7 , color="black" , hj
  annotate("text", x=0.3, y=14, label="(c)", size=10 , color = "black" , hjust = 0.5 , fontface = 2) +
  annotate("text", x=0.34, y=14, label="NDVI[UAS]", size=7 , color = "black" , hjust = 0.5 , parse = T)
  scale_shape_manual(values = c(1:20))

plot_si2
```



plot

sUAS ndre RI

```
sUASndre_yield_mixlm <- lme(fixed = GrainYield_Mgha ~ SI ,
                            random = ~I(SI) | site_year,
                            data = paper3_uas_ndre_data)

summary(sUASndre_yield_mixlm)
```

model

```
## Linear mixed-effects model fit by REML
##   Data: paper3_uas_ndre_data
##        AIC      BIC    logLik
##   603.415 624.1725 -295.7075
##
## Random effects:
##  Formula: ~I(SI) | site_year
##  Structure: General positive-definite, Log-Cholesky parametrization
##             StdDev    Corr
## (Intercept) 3.5144210 (Intr)
## I(SI)       3.6847042 -0.946
## Residual    0.7451118
##
## Fixed effects:  GrainYield_Mgha ~ SI
##                Value Std.Error  DF   t-value p-value
## (Intercept) -0.21627  1.176285 226 -0.183859  0.8543
## SI          11.74458  1.240542 226  9.467298  0.0000
```

```
##  Correlation:
##    (Intr)
## SI -0.951
##
## Standardized Within-Group Residuals:
##          Min           Q1          Med           Q3          Max
## -5.096822800 -0.549578194  0.001105708  0.517734896  2.092222985
##
## Number of Observations: 237
## Number of Groups: 10
```

```
summary(sUASndre_yield_mixlm)$tTable
```

```
##                  Value Std.Error  DF    t-value      p-value
## (Intercept) -0.2162704  1.176285 226 -0.1838588 8.542891e-01
## SI          11.7445785  1.240542 226  9.4672982 3.983273e-18
```

```
Anova(sUASndre_yield_mixlm , type = 2)
```

```
## Analysis of Deviance Table (Type II tests)
##
## Response: GrainYield_Mgha
##    Chisq Df Pr(>Chisq)
## SI 89.63  1  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

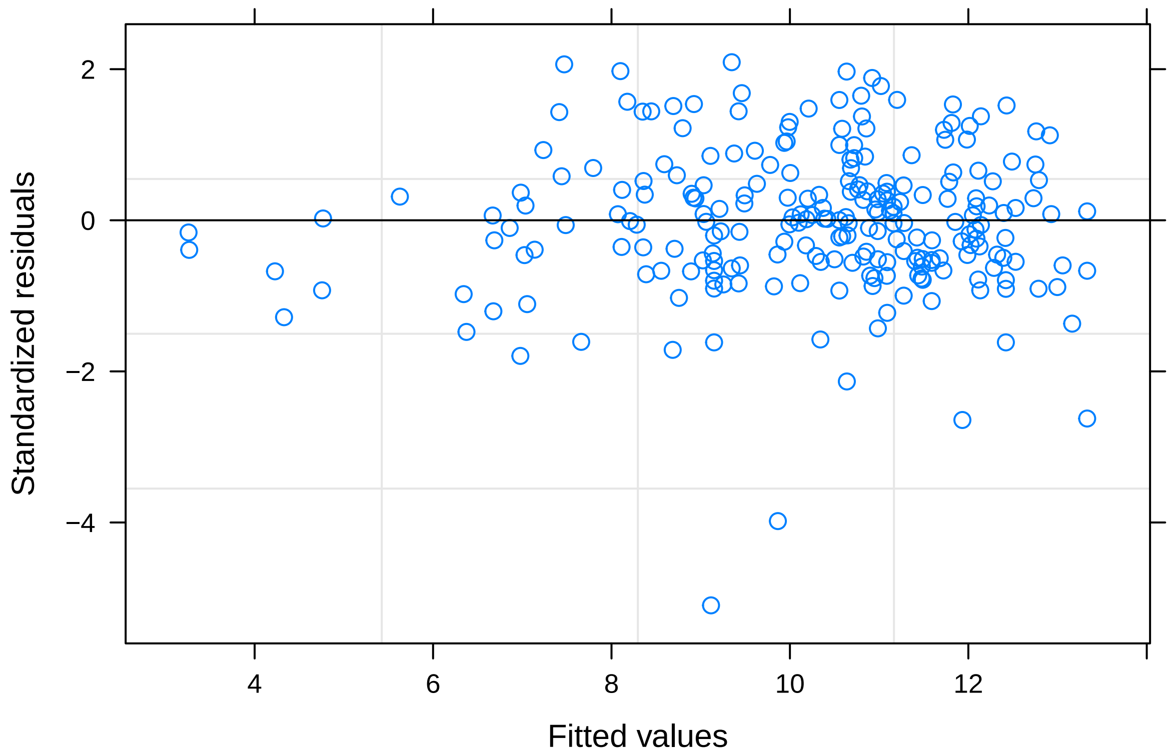
```
Anova(sUASndre_yield_mixlm , type = 3)
```

```
## Analysis of Deviance Table (Type III tests)
##
## Response: GrainYield_Mgha
##               Chisq Df Pr(>Chisq)
## (Intercept)  0.0338  1     0.8541
## SI          89.6297  1     <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
r.squaredGLMM(sUASndre_yield_mixlm)
```

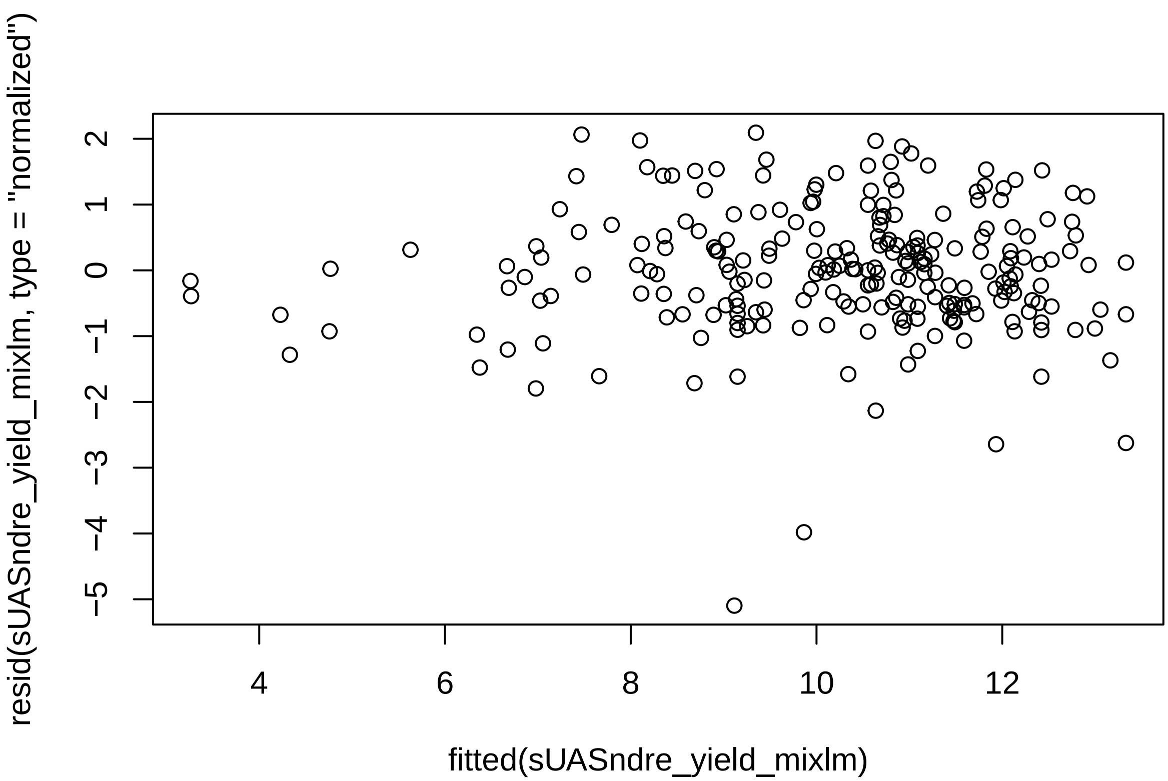
```
##            R2m       R2c
## [1,] 0.5075114 0.8677391
```

```
plot (sUASndre_yield_mixlm)
```



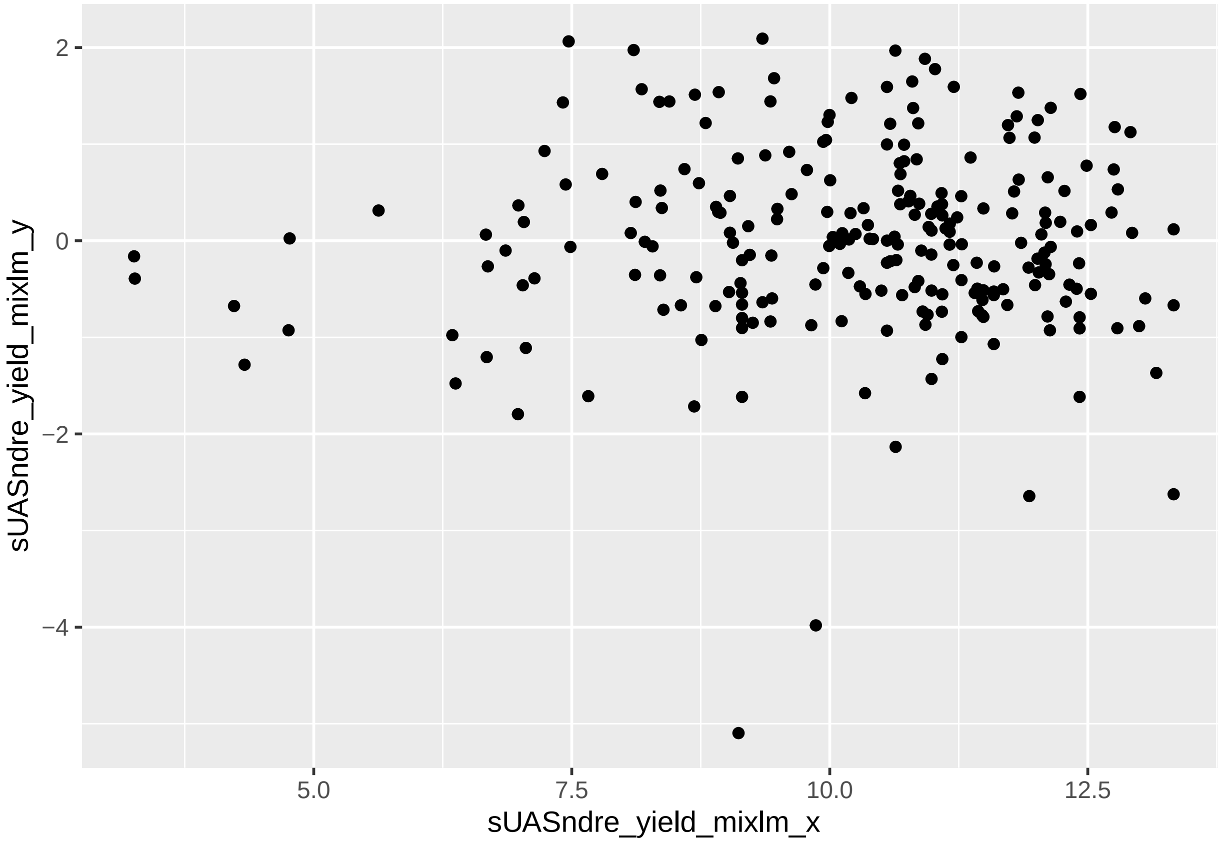
diagnostics

```
plot(resid(sUASndre_yield_mixlm, type = "normalized") ~fitted(sUASndre_yield_mixlm))
```

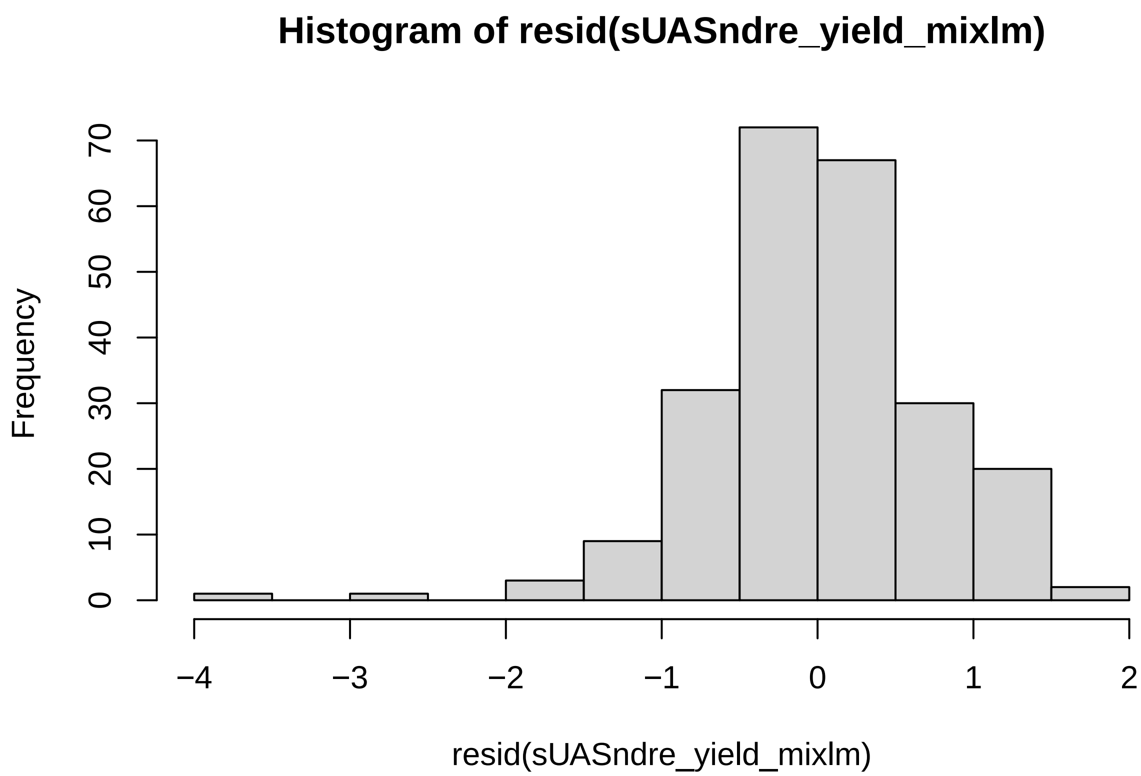



```
sUASndre_yield_mixlm_y <- resid(sUASndre_yield_mixlm, type = "normalized")
sUASndre_yield_mixlm_x <- fitted(sUASndre_yield_mixlm)
```

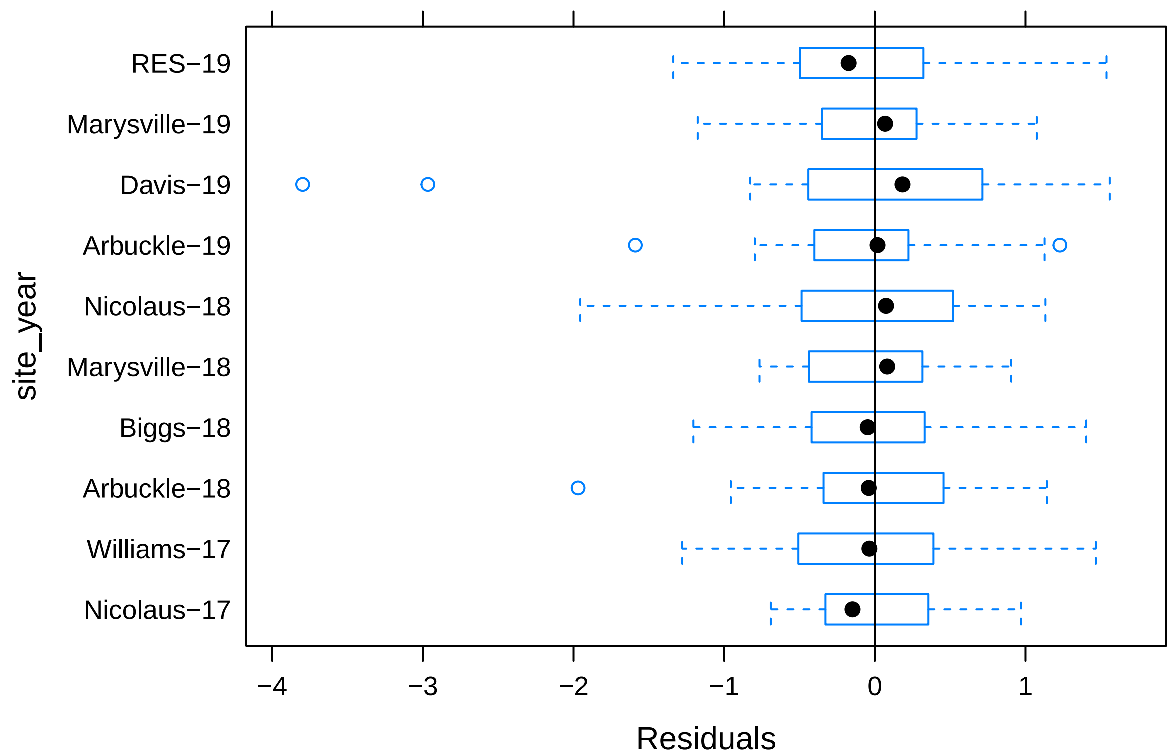
```
sUASndre_yield_mixlmresid_data <- data.frame(sUASndre_yield_mixlm_x , sUASndre_yield_mixlm_y)

ggplot( data = sUASndre_yield_mixlmresid_data , aes( x = sUASndre_yield_mixlm_x , y = sUASndre_yield_mi
  geom_point(mapping = aes(sUASndre_yield_mixlm_x , sUASndre_yield_mixlm_y) , data = sUASndre_yield_mixl
```



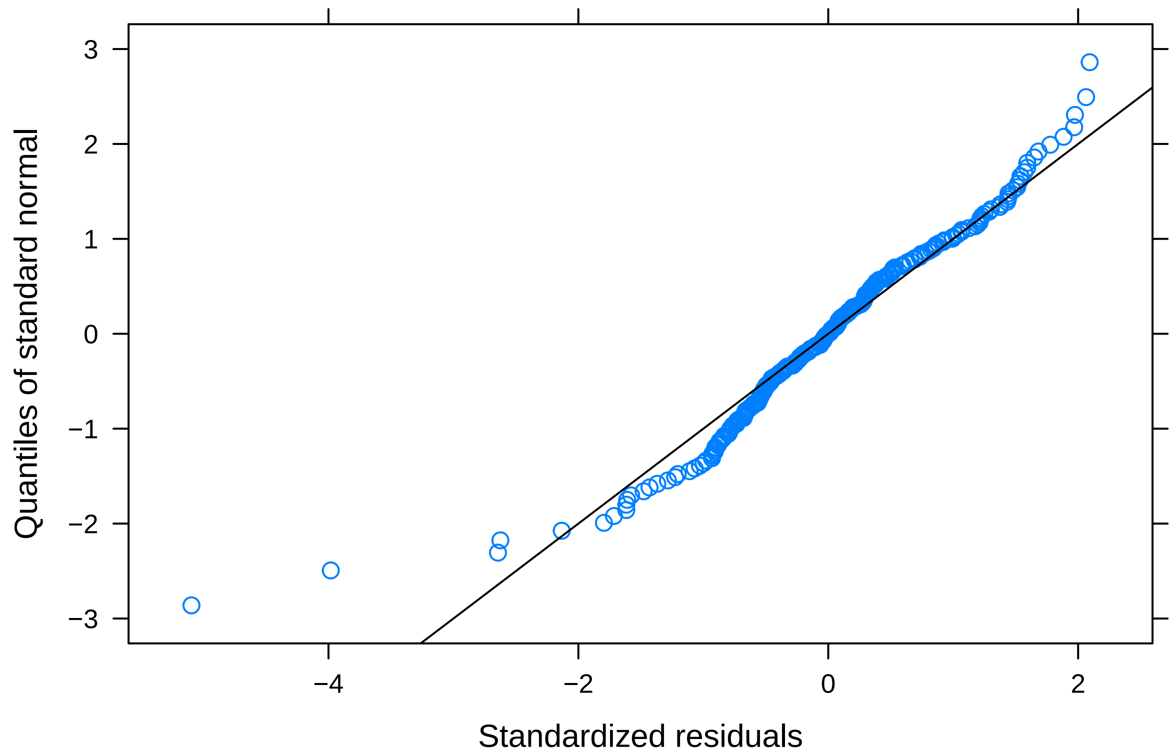

```
hist(resid(sUASndre_yield_mixlm))
```



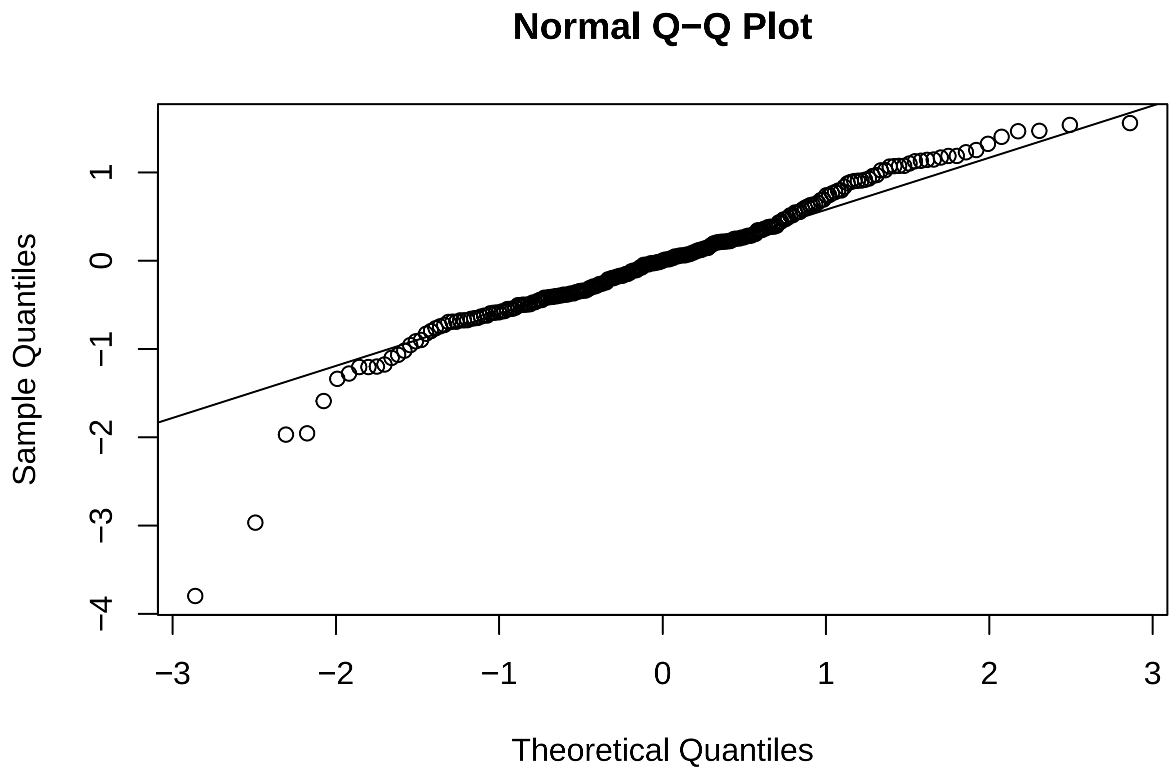

```
plot(sUASndre_yield_mixlm, site_year ~ resid(.), abline = 0)
```



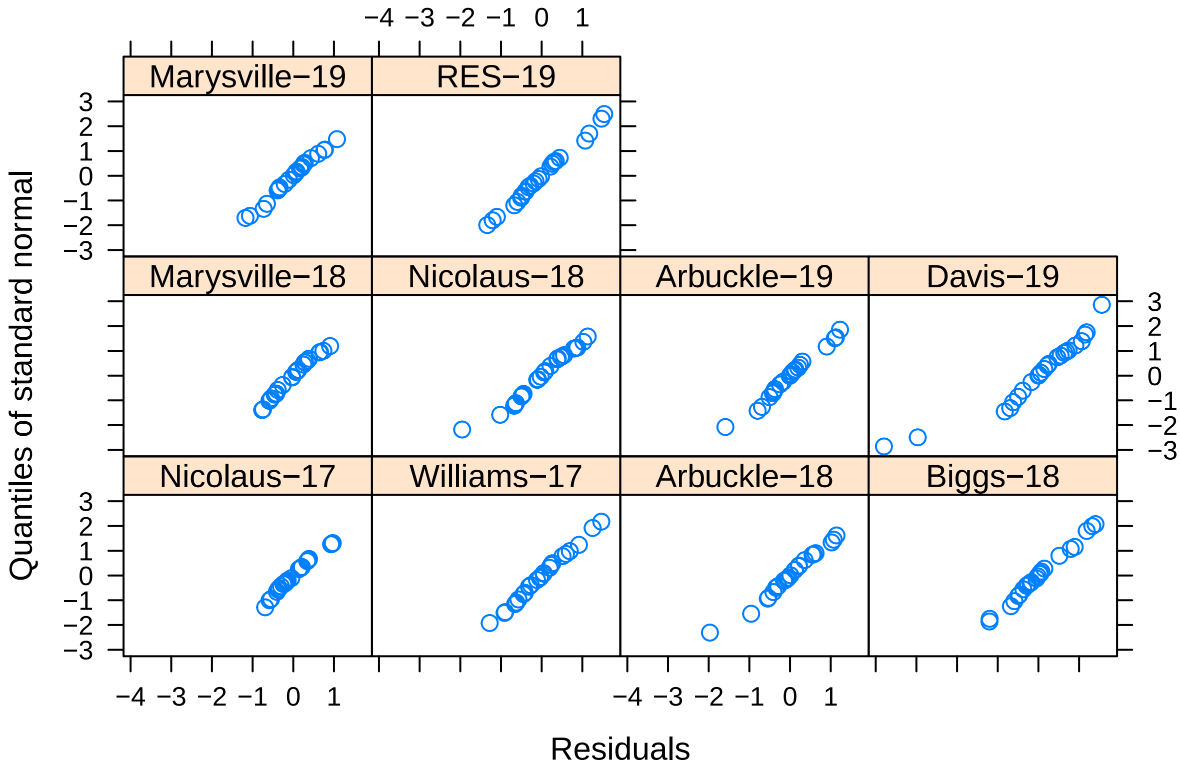

```
qqnorm(sUASndre_yield_mixlm, abline = c(0,1) )
```



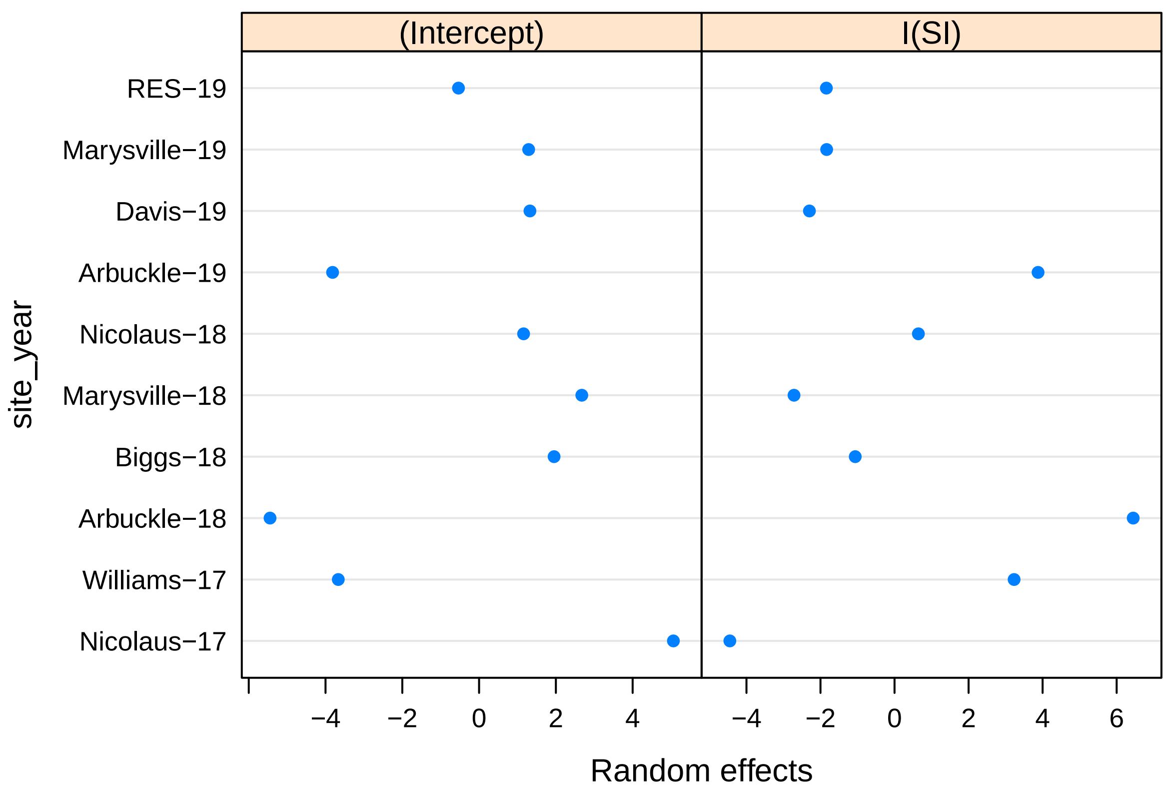

```
qqnorm(resid(sUASndre_yield_mixlm))
qqline(resid(sUASndre_yield_mixlm))
```



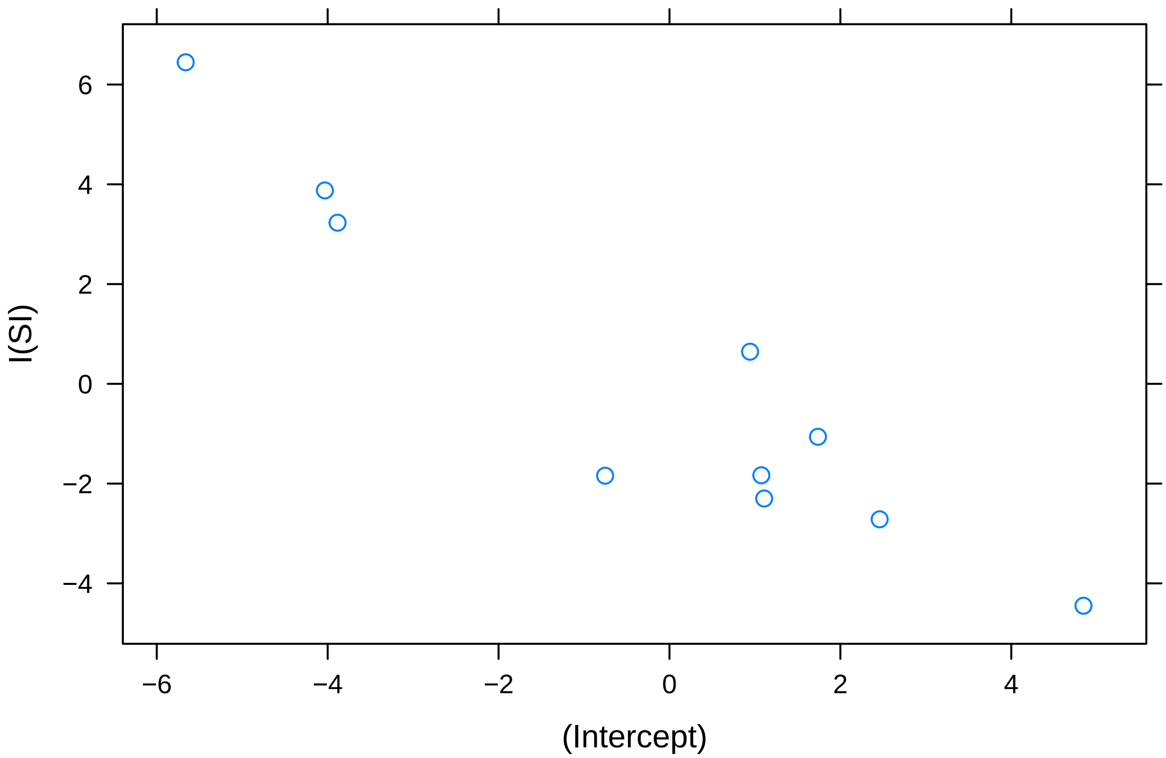

```
qqnorm(sUASndre_yield_mixlm , ~resid(.) | site_year)
```



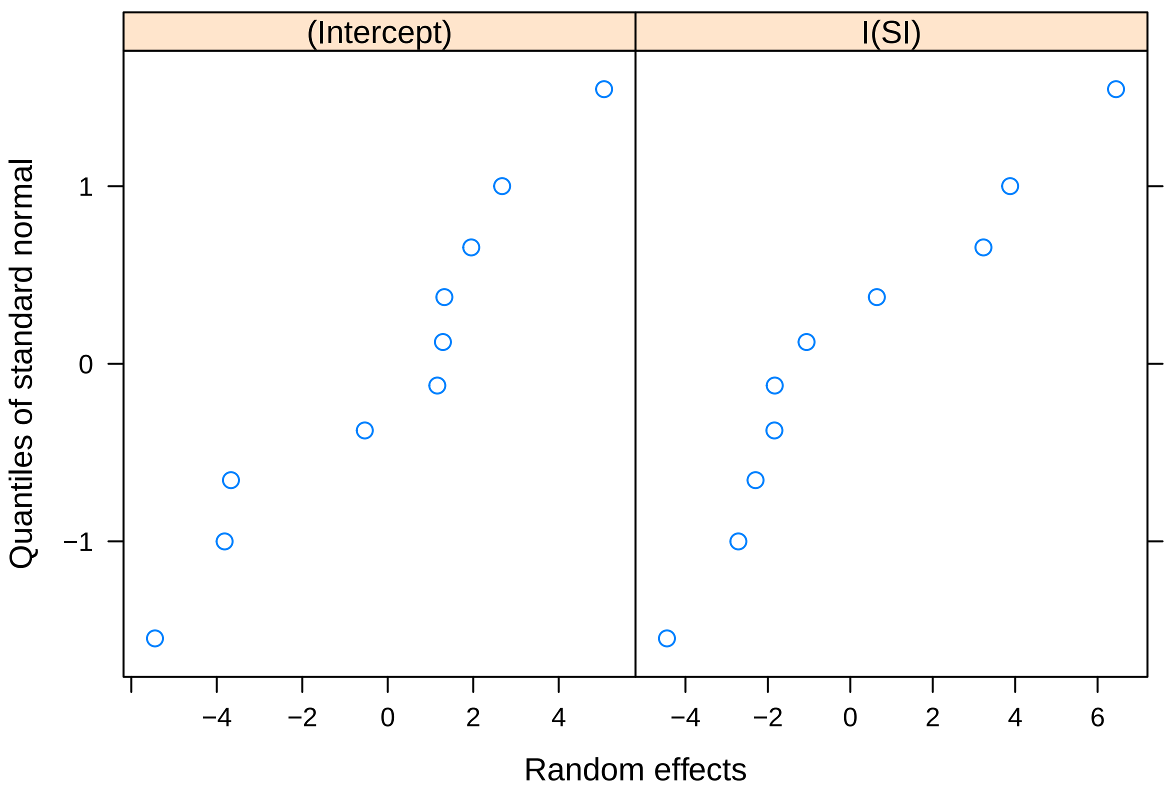

```
plot(ranef(sUASndre_yield_mixlm))
```



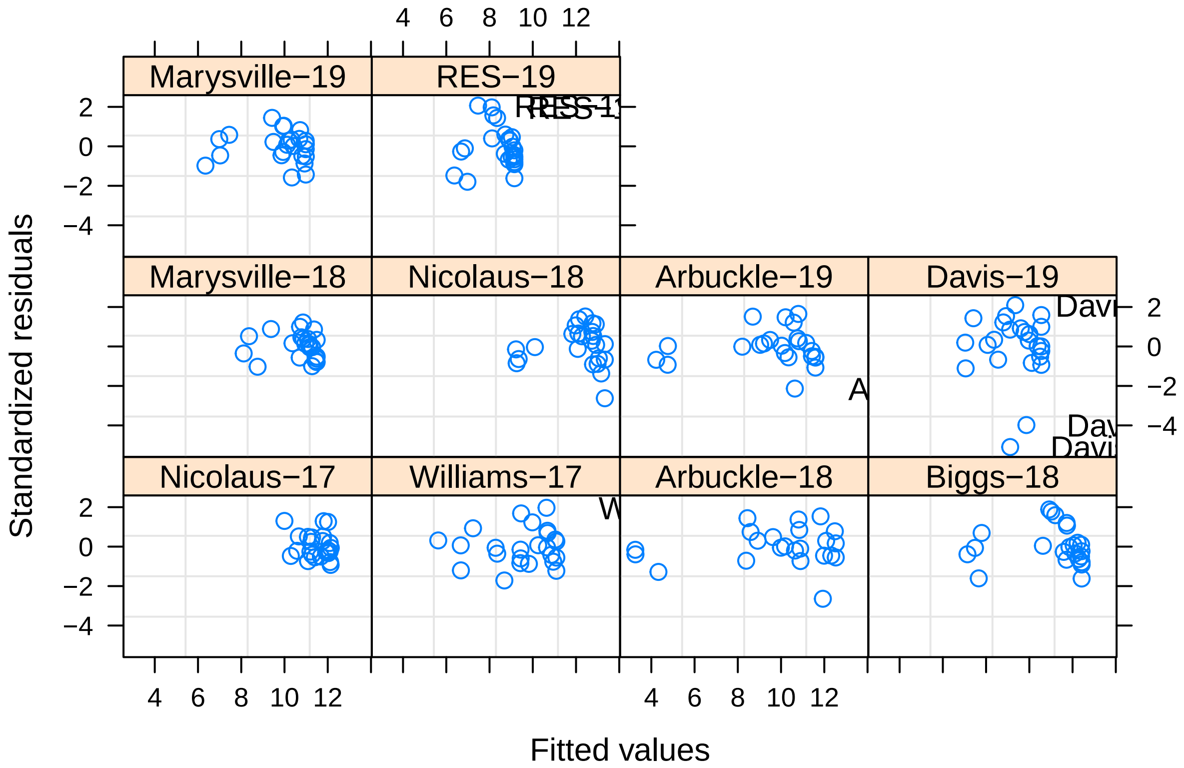

```
pairs(sUASndre_yield_mixlm , id = 0.1)
```




```
qqnorm(sUASndre_yield_mixlm , ~ranef(.))
```



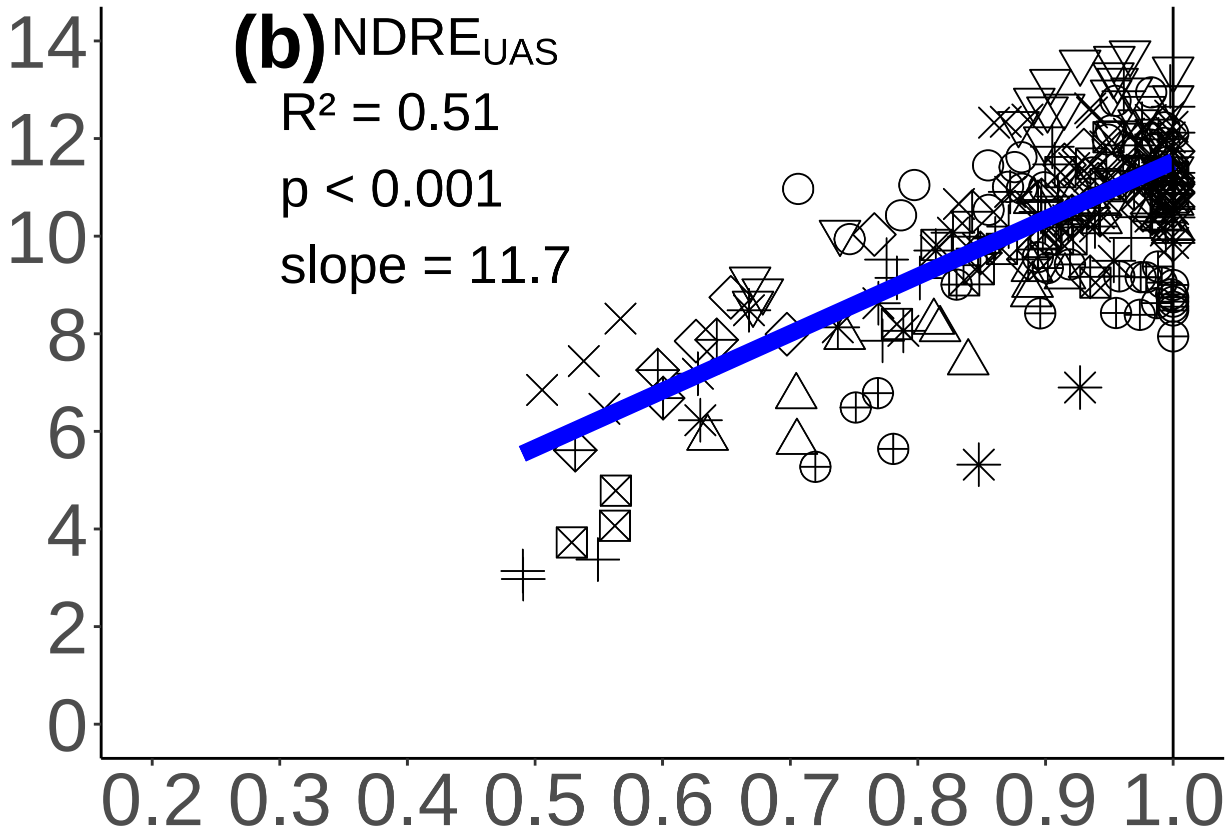

```
plot( sUASndre_yield_mixlm, resid(., type = "p") ~ fitted(.) | site_year,
      id = 0.05, adj = -0.3 )
```




```
mylist <- list(SI=seq(round(min(paper3_uas_ndre_data$SI), digits = 3) , 1 , by = .001))

sUASndre_emmeans <- as.data.frame(summary(emmeans(sUASndre_yield_mixlm , ~ SI , at = mylist )))
```

emmeans

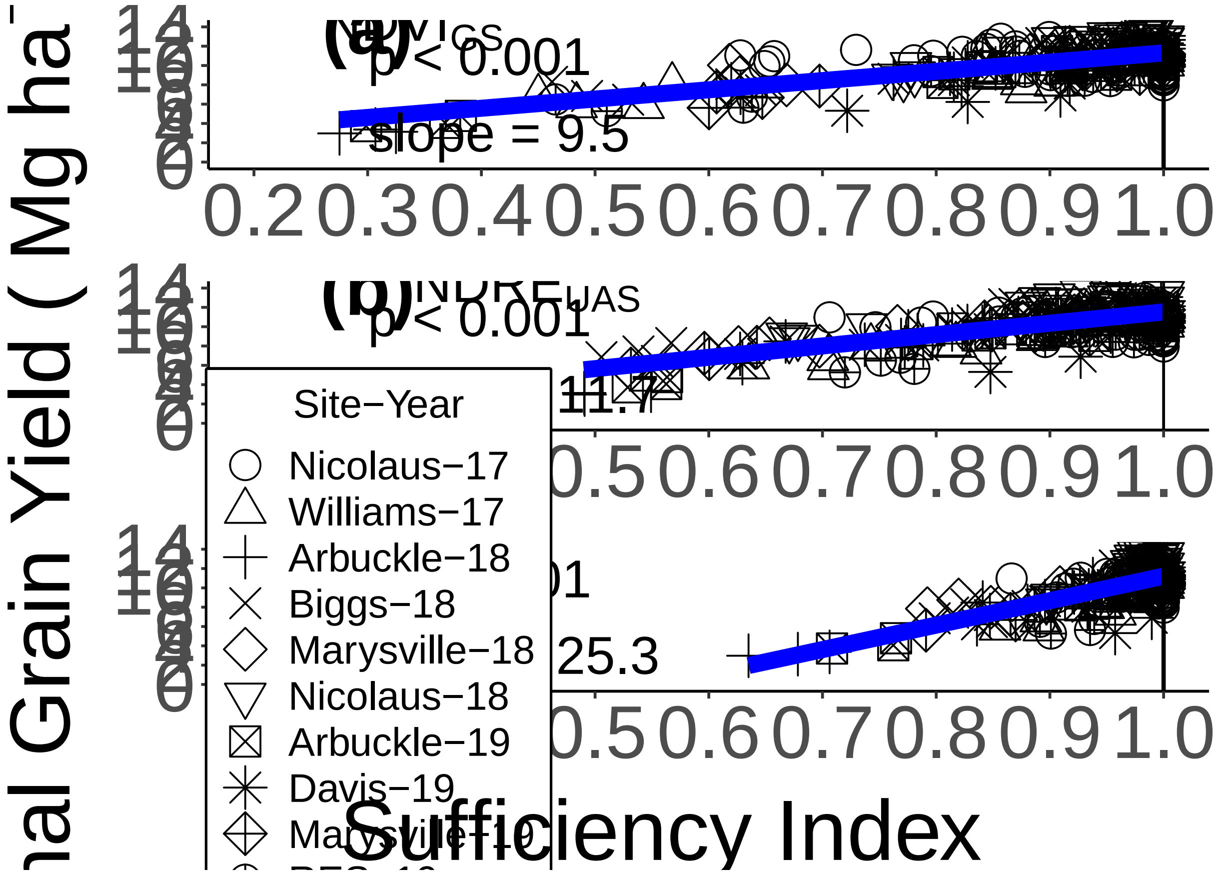
```
plot_si3 <- ggplot( data = paper3_uas_ndre_data , aes( x = SI , y = GrainYield_Mgha)) +
  geom_point( data = paper3_uas_ndre_data , aes( x = SI , y = GrainYield_Mgha , shape = site_year) , si
  geom_line( data = sUASndre_emmeans , aes(x = SI , y = emmean) , color = "blue" , size = 3) +
  theme_classic() +
  labs( x = NULL , y = NULL , shape = "Site-Year") +
  scale_x_continuous(breaks = seq(0.2 , 1 , by = .1)) +
  scale_y_continuous(breaks = seq(0 , 14 , by = 2)) +
  coord_cartesian(ylim = c(0,14) , xlim = c(0.2 , 1)) +
  geom_vline(xintercept = 1 , size = 0.5) +
  theme(axis.text = element_text(size = 28),
        axis.title = element_text(size = 28),
        legend.text = element_text(size = 20),
        legend.title = element_text(size = 20),
        legend.position = "none") +
  annotate("text", x=0.3, y=11, label="R² = 0.51\np < 0.001\nslope = 11.7", size=7 , color = "black" , h
  annotate("text", x=0.3, y=14, label="(b)", size=10 , color = "black" , hjust = 0.5 , fontface = 2) +
  annotate("text", x=0.34, y=14, label="NDRE[UAS]", size=7 , color = "black" , hjust = 0 , parse = T) +
  scale_shape_manual(values = c(1:20))

plot_si3
```



plot

FIGURE 5

```
Fig5 <- grid.arrange(arrangeGrob(plot_si1,
                                 plot_si3,
                                 plot_si2,
                                 nrow = 3,
                                 ncol = 1,
                                 left = textGrob("Final Grain Yield ( Mg ha"^-1~")" , rot = 90 , gp = gp
                                 bottom = textGrob("Sufficiency Index" , gp = gpar(fontsize = 32))))
```




```
ggsave("FIGURES/Fig5.tiff" , Fig5 , compression = "lzw" , width = 22 , height = 22, type = "cairo" , dp
```