

# N Rate Trial (no topdress)

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## Necessary libraries

## Data Organisation

### Read from excel

```

master <- read_excel("master_yields.xlsx", sheet = 1)
master$Treatment <- master$Field
master <- mutate_if(master, is.character, as.factor)
master$NrateF <- as.factor(master$Nrate)
master$Year <- as.factor(master$Year)
master$Yield_Mgha <- master$Yield_kgha/1000
master$Blk <- as.factor(master$Blk)

str(master)

```

```

## tibble [132 x 11] (S3: tbl_df/tbl/data.frame)
##  $ Year          : Factor w/ 3 levels "2021","2022",...: 3 3 3 3 3 3 3 3 3 3 ...
##  $ Plot          : Factor w/ 132 levels "101","102","103",...: 97 98 99 100 101 102 103 104 105 106 .
##  $ Blk           : Factor w/ 9 levels "1","2","3","4",...: 7 7 7 7 7 7 7 7 7 7 ...
##  $ Nrate         : num [1:132] 180 120 150 0 210 90 150 90 120 0 ...
##  $ Field         : Factor w/ 2 levels "CR","FR": 2 2 2 2 2 2 1 1 1 1 ...
##  $ Yield_kgha    : num [1:132] 5264 9982 7902 8451 5596 ...
##  $ Topdress_study: num [1:132] 0 0 0 0 0 0 0 0 0 0 ...
##  $ Topdressed    : Factor w/ 3 levels "0","1","NIL": 3 3 3 3 3 3 3 3 3 3 ...
##  $ Treatment     : Factor w/ 2 levels "CR","FR": 2 2 2 2 2 2 1 1 1 1 ...
##  $ NrateF        : Factor w/ 11 levels "0","90","115",...: 7 4 5 1 9 2 5 2 4 1 ...
##  $ Yield_Mgha    : num [1:132] 5.26 9.98 7.9 8.45 5.6 ...

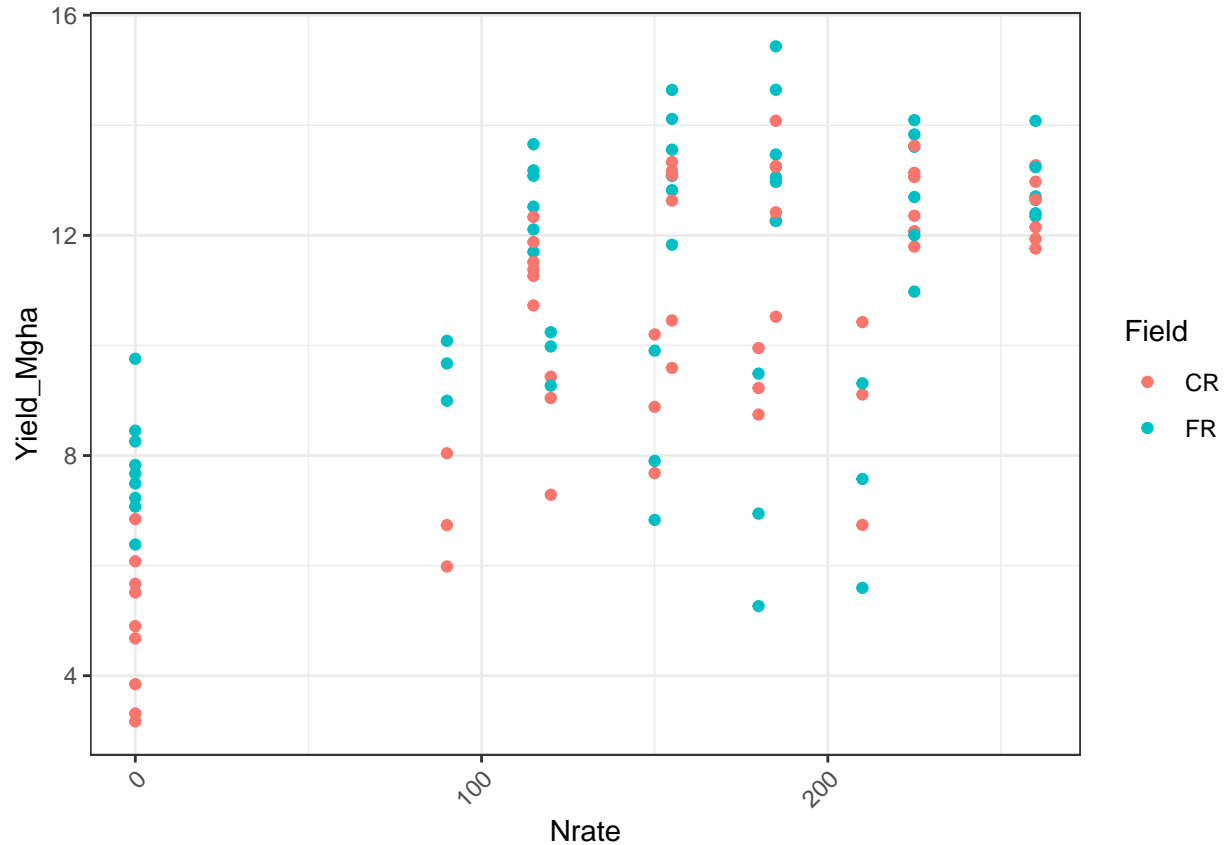
```

## Initial visualisation

```

ggplot(master%>% filter (Topdressed != 1), aes(y=Yield_Mgha, x=Nrate, color=Field))+
  geom_point()+
  theme(axis.text.x = element_text(angle = 45, hjust = 1, size= 9))

```



Subset data from the 3 years

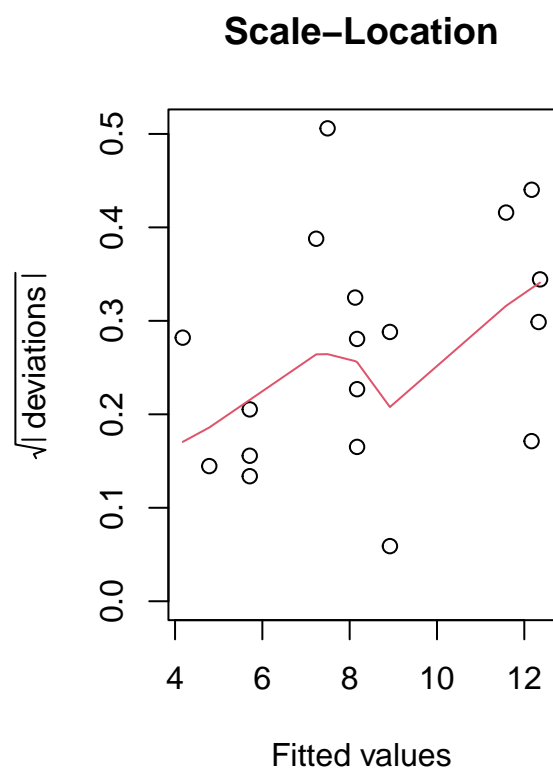
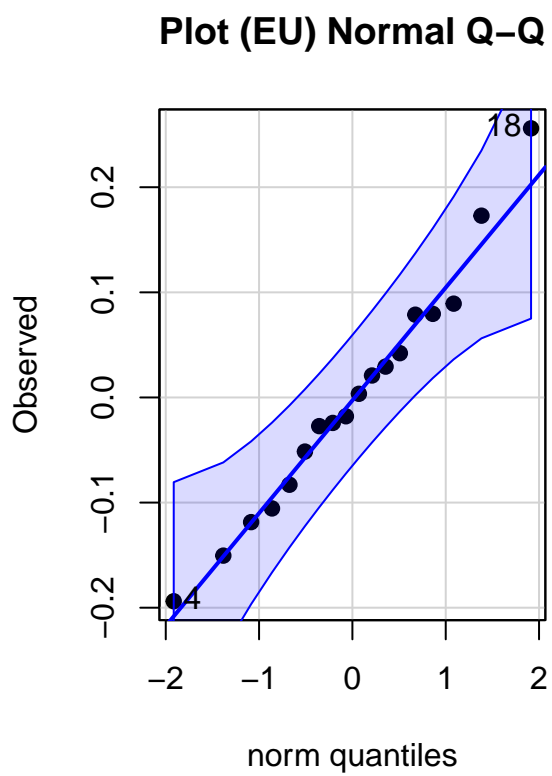
```
#master$main_plot <- paste(master$Blk, master$Treatment, sep="_")
#master$modular <- paste(as.numeric(master$Blk)%3, master$Treatment, sep = "_")
notopdress <- master %>% filter (Topdressed != 1)

yield_average <- notopdress
yield_2021 <- notopdress %>% filter (Year == "2021")
yield_2022 <- notopdress %>% filter (Year == "2022")
yield_2023 <- notopdress %>% filter (Year == "2023")
#checked datasets, all looks good.
```

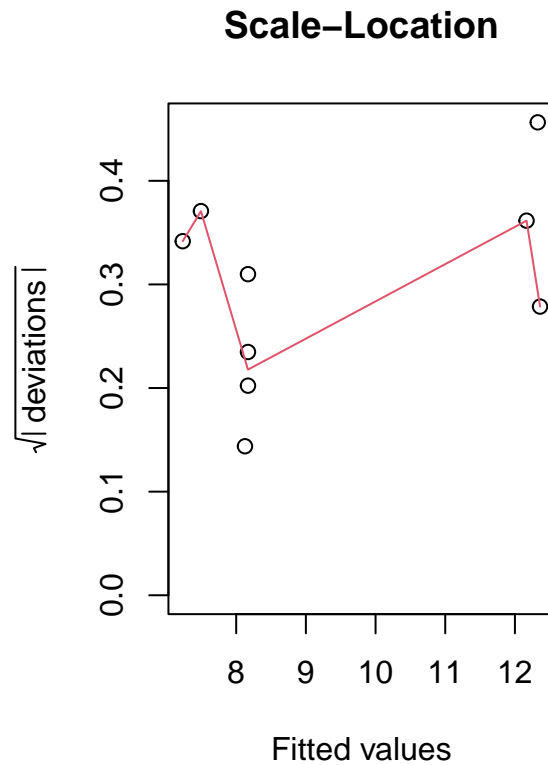
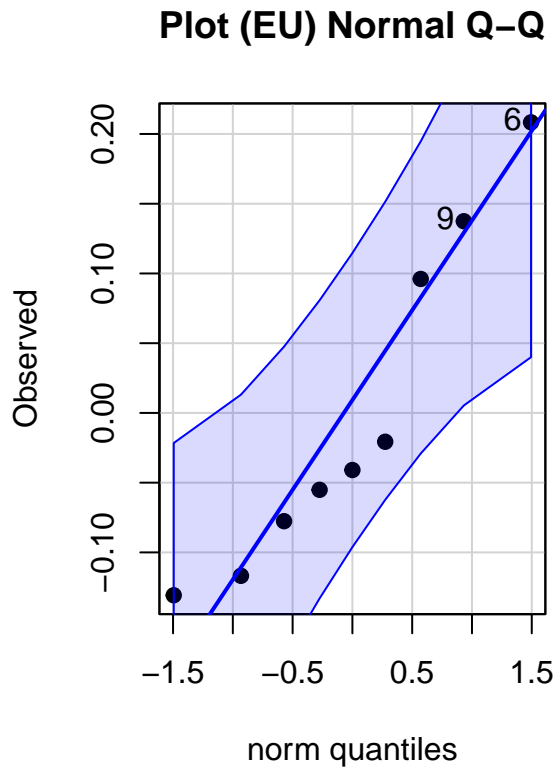
Treatment, Nrate, and year effect (Corresponds to Table 1: ANOVA)

```
model_all_years <- lmer(Yield_Mgha ~ NrateF+Treatment*Year+NrateF:Treatment+Treatment:Year+(1|Blk:Treatment)
#lm(Yield_Mgha ~ Treatment*Year, data = yield_average)

pls205_diagnostics(model_all_years, EU = "Blk:Treatment")
```



```
pls205_diagnostics(model_all_years, EU = "Blk")
```



```
anova(model_all_years)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##               Sum Sq Mean Sq NumDF  DenDF F value    Pr(>F)
## NrateF         427.84  42.784     10  70.000  44.8258 < 2.2e-16 ***
## Treatment         1.80   1.805       1  13.750   1.8908   0.1911
## Year              9.08   4.541       2  11.687   4.7573   0.0308 *
## Treatment:Year     2.36   1.178       2  11.434   1.2346   0.3270
## NrateF:Treatment  51.18   5.118     10  70.000   5.3623 7.657e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
yield_average %>% group_by(Year, Treatment) %>%
  mutate(Yield_Mgha_se = sd(Yield_Mgha)/sqrt(3)) %>%
  summarise(Yield_Mgha = mean(Yield_Mgha),
            Yield_Mgha_se = mean(Yield_Mgha_se))
```

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

```
## # A tibble: 6 x 4
## # Groups:   Year [3]
##   Year Treatment Yield_Mgha Yield_Mgha_se
##   <fct> <fct>         <dbl>         <dbl>
```

##	1	2021	CR	11.6	1.73
##	2	2021	FR	12.7	1.46
##	3	2022	CR	10.6	1.56
##	4	2022	FR	11.6	1.13
##	5	2023	CR	7.78	1.22
##	6	2023	FR	8.41	0.880

## Quadratic models

### Automating the process with functions

We will be assuming that the yield-nrate curve will follow a quadratic curve. It will be messy to extract all the coefficients and then compute local maxima of each treatment. So here is a function to do that.

*#this function automates the extraction of coefficients from quadratic models to calculate optimal N rate*

```
optimal_N <- function(model) {
  # Extract the coefficients
  coefficients <- coef(model)

  # Get the names of the terms to make sure we handle your model's naming conventions
  term_names <- names(coefficients)

  # Identify the names for the intercept, linear, and quadratic terms
  intercept_term <- "(Intercept)"
  linear_term <- term_names[grepl("^Nrate", term_names)]
  quadratic_term <- term_names[grepl("I\\(Nrate\\^2\\)", term_names)]

  # Ensure both linear and quadratic terms are found
  if (length(linear_term) == 0 | length(quadratic_term) == 0) {
    stop("The model must include both Nrate and I(Nrate^2) terms.")
  }

  # Extract individual coefficients
  beta_0 <- coefficients[intercept_term]
  beta_1 <- coefficients[linear_term]
  beta_2 <- coefficients[quadratic_term]

  # Calculate the optimal N rate (x value) where the slope is zero
  x_optimal <- -beta_1 / (2 * beta_2)

  # Calculate the corresponding y value at the optimal N rate
  y_optimal <- beta_0 + beta_1 * x_optimal + beta_2 * x_optimal^2

  # Return both x and y values as a list
  return(list(x_optimal = x_optimal, y_optimal = y_optimal))
}
```

*#this function automates the construction of quadratic models*

```
run_all_models <- function() {
  # Create an empty data frame to store the results
```

```

results <- data.frame(
  Year = character(),
  Treatment = character(),
  Nrate_optimal = numeric(),
  Yield_max = numeric(),
  stringsAsFactors = FALSE
)

# Define the years and treatments
years <- c(2021, 2022, 2023, "average")
treatments <- c("CR", "FR")

# Loop through each year and treatment
for (year in years) {
  for (treatment in treatments) {
    # Construct the model name dynamically
    model_formula <- as.formula(paste0("Yield_Mgha ~ Nrate + I(Nrate^2)"))
    data_name <- paste0("yield_", year)
    model_data <- get(data_name) %>% filter(Treatment == treatment)

    # Fit the model for the current year and treatment
    model <- lm(model_formula, data = model_data)

    # Calculate optimal Nrate and maximum yield using the optimal_N function
    optimal_values <- optimal_N(model)

    # Add the results to the data frame
    results <- rbind(results, data.frame(
      Year = year,
      Treatment = treatment,
      Nrate_optimal = optimal_values$x_optimal,
      Yield_max = optimal_values$y_optimal
    ))
  }
}

return(results)
}

```

## Quadratic regressions and optimal N rates

```

#Here are all the optimal N rates

optimal_results <- run_all_models()

optimal_results

```

##	Year	Treatment	Nrate_optimal	Yield_max
## Nrate	2021	CR	193.27222	13.408929
## Nrate1	2021	FR	188.42729	14.279893
## Nrate2	2022	CR	242.11177	12.336015

```
## Nrate3      2022      FR      188.44741 12.748488
## Nrate4      2023      CR      200.61488  9.067150
## Nrate5      2023      FR       85.28421  9.402874
## Nrate6 average      CR      280.86405 12.321429
## Nrate7 average      FR      281.63233 12.287842
```

```
optimal_results$Year <- as.factor(optimal_results$Year)

quadraticModel_2023_FR <- lm(Yield_Mgha ~ I(Nrate) + I(Nrate^2), data= yield_2023 %>% filter(Treatment==
summary(quadraticModel_2023_FR)
```

```
##
## Call:
## lm(formula = Yield_Mgha ~ I(Nrate) + I(Nrate^2), data = yield_2023 %>%
##   filter(Treatment == "FR"))
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -2.7073 -0.7673  0.1337  0.7495  2.3905
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  8.2422941   0.7652302  10.771 1.86e-08 ***
## I(Nrate)      0.0272168   0.0149453   1.821  0.0886 .
## I(Nrate^2)   -0.0001596   0.0000687  -2.323  0.0347 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.342 on 15 degrees of freedom
## Multiple R-squared:  0.3162, Adjusted R-squared:  0.2251
## F-statistic: 3.469 on 2 and 15 DF,  p-value: 0.05779
```

```
write_xlsx(optimal_results, "C:/Users/zhang/Documents/GitHub/FallowRice-ContinuousRice_AgronomicPerform
```

## Data visualisation and statistical testing (Corresponds to Figure 2)

### Graphing dataframes

```
# 2021 dataframe

yield_2021_dataframe <- yield_2021 %>%
  group_by(Treatment, Nrate) %>%
  mutate(Yield_Mgha_se = sd(Yield_Mgha)/sqrt(3)) %>%
  summarise(Yield_Mgha = mean(Yield_Mgha),
            Yield_Mgha_se = mean(Yield_Mgha_se)) %>%
  mutate(Year = "2021") %>%
  left_join(optimal_results %>% select(Year, Treatment, Nrate_optimal), by = c("Year", "Treatment")) %>%
  mutate(Nrate_optimal = round(Nrate_optimal))
```



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

```
# 2022 dataframe
```

```
yield_2022_dataframe <- yield_2022 %>%
  group_by(Treatment, Nrate) %>%
  mutate(Yield_Mgha_se = sd(Yield_Mgha)/sqrt(3)) %>%
  summarise(Yield_Mgha = mean(Yield_Mgha),
            Yield_Mgha_se = mean(Yield_Mgha_se)) %>%
  mutate(Year = "2022") %>%
  left_join(optimal_results %>% select(Year, Treatment, Nrate_optimal), by = c("Year", "Treatment")) %>%
  mutate(Nrate_optimal = round(Nrate_optimal))
```

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

```
# 2023 dataframe
```

```
yield_2023_dataframe <- yield_2023 %>%
  group_by(Treatment, Nrate) %>%
  mutate(Yield_Mgha_se = sd(Yield_Mgha)/sqrt(3)) %>%
  summarise(Yield_Mgha = mean(Yield_Mgha),
            Yield_Mgha_se = mean(Yield_Mgha_se)) %>%
  mutate(Year = "2023") %>%
  left_join(optimal_results %>% select(Year, Treatment, Nrate_optimal), by = c("Year", "Treatment")) %>%
  mutate(Nrate_optimal = round(Nrate_optimal))
```

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

```
# average dataframe
```

```
yield_average_dataframe <- yield_average %>%
  group_by(Treatment, Nrate) %>%
  mutate(Yield_Mgha_se = sd(Yield_Mgha)/sqrt(3)) %>%
  summarise(Yield_Mgha = mean(Yield_Mgha),
            Yield_Mgha_se = mean(Yield_Mgha_se)) %>%
  mutate(Year = "average") %>%
  left_join(optimal_results %>% select(Year, Treatment, Nrate_optimal), by = c("Year", "Treatment")) %>%
  mutate(Nrate_optimal = round(Nrate_optimal))
```

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

## 2021

Statical test, comparisons by N rate and Treatment

```
model_2021 <- lmer(Yield_Mgha ~ NrateF*Treatment+(1|Blk:Treatment)+(1|Blk), data=yield_2021)
```

```
## boundary (singular) fit: see help('isSingular')
```

```
anova(model_2021)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##              Sum Sq Mean Sq NumDF DenDF  F value    Pr(>F)
## NrateF          251.041   50.208     5     22 163.6431 < 2.2e-16 ***
## Treatment        12.176   12.176     1     22  39.6860 2.436e-06 ***
## NrateF:Treatment   2.236    0.447     5     22   1.4574   0.2437
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
field_means_2021 = emmeans(model_2021,spec = 'Treatment',by = 'NrateF')
field_effects_2021 = contrast(field_means_2021, method = 'pairwise', adjust = "Tukey")
```

```
summary(field_effects_2021)
```

```
## NrateF = 0:
## contrast estimate      SE    df t.ratio p.value
## CR - FR      -2.246 0.452 20.6  -4.965  0.0001
##
## NrateF = 115:
## contrast estimate      SE    df t.ratio p.value
## CR - FR      -1.177 0.452 20.6  -2.603  0.0168
##
## NrateF = 155:
## contrast estimate      SE    df t.ratio p.value
## CR - FR      -0.904 0.452 20.6  -2.000  0.0589
##
## NrateF = 185:
## contrast estimate      SE    df t.ratio p.value
## CR - FR      -0.988 0.452 20.6  -2.184  0.0407
##
## NrateF = 225:
## contrast estimate      SE    df t.ratio p.value
## CR - FR      -0.806 0.452 20.6  -1.781  0.0897
##
## NrateF = 260:
## contrast estimate      SE    df t.ratio p.value
## CR - FR      -0.858 0.452 20.6  -1.897  0.0719
##
## Degrees-of-freedom method: kenward-roger
```

```
cld(field_means_2021)
```

```
## NrateF = 0:
## Treatment emmean      SE    df lower.CL upper.CL .group
## CR          5.22 0.338 21.5     4.52     5.92     1
```

```

## FR          7.46 0.338 21.5      6.76      8.17    2
##
## NrateF = 115:
## Treatment emmean    SE    df lower.CL upper.CL .group
## CR          11.91 0.338 21.5     11.21    12.61    1
## FR          13.09 0.338 21.5     12.39    13.79    2
##
## NrateF = 155:
## Treatment emmean    SE    df lower.CL upper.CL .group
## CR          13.20 0.338 21.5     12.50    13.90    1
## FR          14.10 0.338 21.5     13.40    14.81    1
##
## NrateF = 185:
## Treatment emmean    SE    df lower.CL upper.CL .group
## CR          13.53 0.338 21.5     12.83    14.23    1
## FR          14.52 0.338 21.5     13.82    15.22    2
##
## NrateF = 225:
## Treatment emmean    SE    df lower.CL upper.CL .group
## CR          13.04 0.338 21.5     12.34    13.74    1
## FR          13.85 0.338 21.5     13.14    14.55    1
##
## NrateF = 260:
## Treatment emmean    SE    df lower.CL upper.CL .group
## CR          12.46 0.338 21.5     11.76    13.16    1
## FR          13.32 0.338 21.5     12.62    14.02    1
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.

```

```

emmeans(model_2021, ~ Treatment + NrateF)

```

```

## Treatment NrateF emmean    SE    df lower.CL upper.CL
## CR         0       5.22 0.338 21.5     4.52     5.92
## FR         0       7.46 0.338 21.5     6.76     8.17
## CR        115     11.91 0.338 21.5     11.21    12.61
## FR        115     13.09 0.338 21.5     12.39    13.79
## CR        155     13.20 0.338 21.5     12.50    13.90
## FR        155     14.10 0.338 21.5     13.40    14.81
## CR        185     13.53 0.338 21.5     12.83    14.23
## FR        185     14.52 0.338 21.5     13.82    15.22
## CR        225     13.04 0.338 21.5     12.34    13.74
## FR        225     13.85 0.338 21.5     13.14    14.55
## CR        260     12.46 0.338 21.5     11.76    13.16
## FR        260     13.32 0.338 21.5     12.62    14.02
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95

```

```
cld_2021 <- cld(emmeans(model_2021, ~ Treatment + NrateF), adjust = "Sidak")
```

```
cld_2021
```

```
## Treatment NrateF emmean SE df lower.CL upper.CL .group
## CR 0 5.22 0.338 21.5 4.14 6.30 1
## FR 0 7.46 0.338 21.5 6.39 8.54 2
## CR 115 11.91 0.338 21.5 10.83 12.99 3
## CR 260 12.46 0.338 21.5 11.38 13.54 34
## CR 225 13.04 0.338 21.5 11.96 14.12 345
## FR 115 13.09 0.338 21.5 12.01 14.17 345
## CR 155 13.20 0.338 21.5 12.12 14.28 345
## FR 260 13.32 0.338 21.5 12.24 14.40 345
## CR 185 13.53 0.338 21.5 12.45 14.61 345
## FR 225 13.85 0.338 21.5 12.77 14.92 45
## FR 155 14.10 0.338 21.5 13.03 15.18 45
## FR 185 14.52 0.338 21.5 13.44 15.59 5
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## Conf-level adjustment: sidak method for 12 estimates
## P value adjustment: sidak method for 66 tests
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
## then we cannot show them to be different.
## But we also did not show them to be the same.
```

```
top_yields_2021 <- cld_2021 %>%
  group_by(Treatment) %>%
  filter(emmean == max(emmean)) %>%
  ungroup()
```

## Graph\_2021

```
N_response_curve_2021 <-
ggplot(yield_2021_dataframe, aes(x=Nrate, y=Yield_Mgha, color=Treatment))+
  geom_point(data=yield_2021_dataframe, size=2.5)+ #this is the mean values
  geom_point(data=yield_2021, size=1, alpha=0.4)+ #this are the raw values
  scale_color_manual(values=c("#0072B2", "#FF9900"), name = "Treatment", labels = c('Continuous Rice (CR)', 'Fertilizer Rice (FR)'))
  scale_x_continuous(name=expression("N rate (kg N ha"^{-1}*")"), limits = c(-20, 320), breaks = seq(0, 320, 20),
  #scale_x_continuous(name=expression("N rate (kg N ha"^{-1}*")"), limits = c(-20, 280), breaks = c(0, 115, 155, 185, 225, 260))
  scale_y_continuous(name= expression("Yield (Mg ha"^{-1}*")"), limits = c(0, 22), breaks = seq(0, 22, 1))
  #geom_errorbar(data=yield_2021_dataframe, aes(ymin=Yield_Mgha-Yield_Mgha_se, ymax=Yield_Mgha+Yield_Mgha_se))
  theme_classic()+
  geom_smooth(data = yield_2021, method = "lm", formula = y ~ poly(x, 2), se = FALSE)+
  #geom_vline(xintercept = c(0, 115, 155, 185, 225, 260), linetype = "twodash", color = "black") +
  stat_regline_equation(data=yield_2021,
    aes(x=Nrate, y=Yield_Mgha, color=Treatment, group = Treatment,
      label = paste(..rr.label..)),
    formula = y ~ poly(x, 2, raw = TRUE),
    show.legend = FALSE, label.x = 0, label.y = c(16.5, 19))+
```

```

stat_regline_equation(data=yield_2021,
                      aes(x=Nrate, y=Yield_Mgha, color=Treatment, group = Treatment,
                          label = paste(..eq.label..)),
                      formula = y ~ poly(x, 2, raw = TRUE),
                      show.legend = FALSE, label.x = 0, label.y = c(17.5, 20))+
theme(axis.text = element_text(size = 14), axis.title = element_text(size=16))+
theme(legend.text = element_text(size = 16), legend.title = element_text(size = 18))+
theme(plot.title = element_text(hjust = 0.5, size = 20, face = "bold"))+
ggtitle(expression("2021"))+
annotate(
  "text",
  x = c(0),
  y = yield_2021_dataframe %>%
    filter(Treatment == "FR", Nrate == 0) %>%
    mutate(Yield_Mgha_plus_higher = Yield_Mgha + 1) %>%
    pull(Yield_Mgha_plus_higher),
  label = "*",
  size = 7,
  vjust = 0
)+
# Vertical line for CR
geom_segment(
  aes(x = optimal_results %>% filter(Treatment == "CR", Year == "2021") %>% pull(Nrate_optimal),
      xend = optimal_results %>% filter(Treatment == "CR", Year == "2021") %>% pull(Nrate_optimal),
      y = 0, # Start exactly from 0 on y-axis
      yend = optimal_results %>% filter(Treatment == "CR", Year == "2021") %>% pull(Yield_max)),
  linetype = "twodash", color = "#0072B2", size = 0.6
) +
# Vertical line for FR
geom_segment(
  aes(x = optimal_results %>% filter(Treatment == "FR", Year == "2021") %>% pull(Nrate_optimal),
      xend = optimal_results %>% filter(Treatment == "FR", Year == "2021") %>% pull(Nrate_optimal),
      y = 0, # Start exactly from 0 on y-axis
      yend = optimal_results %>% filter(Treatment == "FR", Year == "2021") %>% pull(Yield_max)),
  linetype = "twodash", color = "#FF9900", size = 0.6
) +
# Horizontal line for CR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "CR", Year == "2021") %>% pull(Yield_max),
      yend = optimal_results %>% filter(Treatment == "CR", Year == "2021") %>% pull(Yield_max),
      x = -20, # Start exactly from 0 on x-axis
      xend = optimal_results %>% filter(Treatment == "CR", Year == "2021") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#0072B2", size = 0.6
) +
# Horizontal line for FR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "FR", Year == "2021") %>% pull(Yield_max),
      yend = optimal_results %>% filter(Treatment == "FR", Year == "2021") %>% pull(Yield_max),
      x = -20, # Start exactly from 0 on x-axis
      xend = optimal_results %>% filter(Treatment == "FR", Year == "2021") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#FF9900", size = 0.6
)+

```

```

geom_curve(x = top_yields_2021 %>%
  filter(Treatment == "FR") %>%
  mutate(NrateF = as.numeric(paste(NrateF))) %>%
  pull(NrateF)-2,
  y = top_yields_2021 %>%
  filter(Treatment == "FR") %>%
  pull(emmean),
  xend = top_yields_2021 %>%
  filter(Treatment == "CR") %>%
  mutate(NrateF = as.numeric(paste(NrateF))) %>%
  pull(NrateF)-2,
  yend = top_yields_2021 %>%
  filter(Treatment == "CR") %>%
  pull(emmean),
  color = 1, size=1,
  curvature = 1.2,)+
annotate(
  "text",
  x = (top_yields_2021 %>%
    filter(Treatment == "FR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF)+
    top_yields_2021 %>%
    filter(Treatment == "CR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF))/2,
  y = (top_yields_2021 %>%
    filter(Treatment == "FR") %>%
    pull(emmean)+
    top_yields_2021 %>%
    filter(Treatment == "CR") %>%
    pull(emmean))/2,
  label = "ns",
  size = 5,
  vjust = 0.3,
  hjust = +2.2 )

```

```

## Warning: Using 'size' aesthetic for lines was deprecated in ggplot2 3.4.0.
## i Please use 'linewidth' instead.
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.

```

N\_response\_curve\_2021

```

## Warning: The dot-dot notation ('..rr.label..') was deprecated in ggplot2 3.4.0.
## i Please use 'after_stat(rr.label)' instead.
## This warning is displayed once every 8 hours.
## Call 'lifecycle::last_lifecycle_warnings()' to see where this warning was
## generated.

```

```

## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length

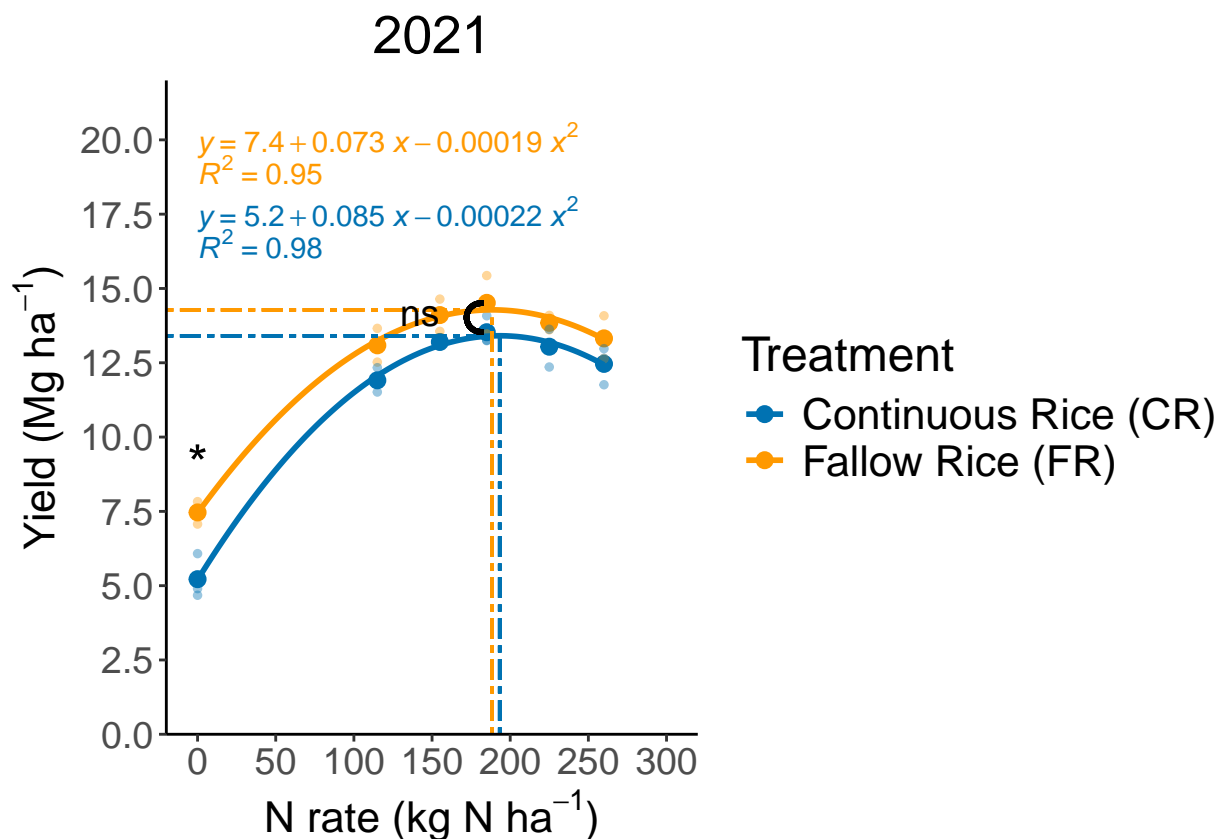
```

```
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```



2022

Statistical test, comparisons by N rate and Treatment

```
model_2022 <- lmer(Yield_Mgha ~ NrateF*Treatment+(1|Blk:Treatment)+(1|Blk), data=yield_2022)
anova(model_2022)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##               Sum Sq Mean Sq NumDF DenDF F value    Pr(>F)
## NrateF         155.079  31.0159     5    20 37.7791 1.601e-09 ***
## Treatment         5.857   5.8567     1     2  7.1338  0.1162
## NrateF:Treatment   8.633   1.7265     5    20  2.1030  0.1073
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
field_means_2022 = emmeans(model_2022, spec = 'Treatment', by = 'NrateF')
field_effects_2022 = contrast(field_means_2022, method = 'pairwise', adjust = "Tukey")

summary(field_effects_2022)
```

```
## NrateF = 0:
## contrast estimate SE df t.ratio p.value
## CR - FR      -2.5151 0.774 17.4  -3.251  0.0046
##
## NrateF = 115:
## contrast estimate SE df t.ratio p.value
## CR - FR      -1.2073 0.774 17.4  -1.561  0.1366
##
## NrateF = 155:
## contrast estimate SE df t.ratio p.value
## CR - FR      -1.6841 0.774 17.4  -2.177  0.0435
##
## NrateF = 185:
## contrast estimate SE df t.ratio p.value
## CR - FR      -1.0247 0.774 17.4  -1.325  0.2024
##
## NrateF = 225:
## contrast estimate SE df t.ratio p.value
## CR - FR       0.4174 0.774 17.4   0.540  0.5963
##
## NrateF = 260:
## contrast estimate SE df t.ratio p.value
## CR - FR      -0.0308 0.774 17.4  -0.040  0.9686
##
## Degrees-of-freedom method: kenward-roger
```

```
cld(field_means_2022)
```

```
## NrateF = 0:
## Treatment emmean SE df lower.CL upper.CL .group
## CR         5.28 0.6 16.4    4.01    6.54  1
## FR         7.79 0.6 16.4    6.52    9.06  2
##
## NrateF = 115:
## Treatment emmean SE df lower.CL upper.CL .group
## CR        11.12 0.6 16.4    9.85   12.39  1
## FR        12.33 0.6 16.4   11.06   13.60  1
##
## NrateF = 155:
## Treatment emmean SE df lower.CL upper.CL .group
```



```
## CR      10.89 0.6 16.4      9.62      12.16 1
## FR      12.58 0.6 16.4     11.31      13.85 2
##
## NrateF = 185:
## Treatment emmean SE    df lower.CL upper.CL .group
## CR      11.74 0.6 16.4     10.47      13.01 1
## FR      12.76 0.6 16.4     11.49      14.03 1
##
## NrateF = 225:
## Treatment emmean SE    df lower.CL upper.CL .group
## FR      11.89 0.6 16.4     10.62      13.16 1
## CR      12.31 0.6 16.4     11.04      13.58 1
##
## NrateF = 260:
## Treatment emmean SE    df lower.CL upper.CL .group
## CR      12.45 0.6 16.4     11.18      13.72 1
## FR      12.48 0.6 16.4     11.22      13.75 1
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
emmeans(model_2022, ~ Treatment + NrateF)
```

```
## Treatment NrateF emmean SE    df lower.CL upper.CL
## CR      0      5.28 0.6 16.4     4.01      6.54
## FR      0      7.79 0.6 16.4     6.52      9.06
## CR     115     11.12 0.6 16.4     9.85     12.39
## FR     115     12.33 0.6 16.4    11.06     13.60
## CR     155     10.89 0.6 16.4     9.62     12.16
## FR     155     12.58 0.6 16.4    11.31     13.85
## CR     185     11.74 0.6 16.4    10.47     13.01
## FR     185     12.76 0.6 16.4    11.49     14.03
## CR     225     12.31 0.6 16.4    11.04     13.58
## FR     225     11.89 0.6 16.4    10.62     13.16
## CR     260     12.45 0.6 16.4    11.18     13.72
## FR     260     12.48 0.6 16.4    11.22     13.75
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
```

```
cld_2022 <- cld(emmeans(model_2022, ~ Treatment + NrateF),adjust = "Sidak")
```

```
cld_2022
```

```
## Treatment NrateF emmean SE    df lower.CL upper.CL .group
## CR      0      5.28 0.6 16.4     3.29      7.26 1
## FR      0      7.79 0.6 16.4     5.80      9.78 12
## CR     155     10.89 0.6 16.4     8.90     12.88 23
## CR     115     11.12 0.6 16.4     9.14     13.11 3
```

```
## CR      185      11.74 0.6 16.4      9.75      13.73      3
## FR      225      11.89 0.6 16.4      9.91      13.88      3
## CR      225      12.31 0.6 16.4      10.32      14.30      3
## FR      115      12.33 0.6 16.4      10.34      14.32      3
## CR      260      12.45 0.6 16.4      10.47      14.44      3
## FR      260      12.48 0.6 16.4      10.50      14.47      3
## FR      155      12.58 0.6 16.4      10.59      14.56      3
## FR      185      12.76 0.6 16.4      10.77      14.75      3
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## Conf-level adjustment: sidak method for 12 estimates
## P value adjustment: sidak method for 66 tests
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
top_yields_2022 <- cld_2022 %>%
  group_by(Treatment) %>%
  filter(emmean == max(emmean)) %>%
  ungroup()

top_yields_2022
```

```
## # A tibble: 2 x 8
##   Treatment NrateF emmean   SE    df lower.CL upper.CL .group
##   <fct>      <fct>   <dbl> <dbl> <dbl>   <dbl>   <dbl> <chr>
## 1 CR      260      12.5 0.600  16.4    10.5    14.4 " 3"
## 2 FR      185      12.8 0.600  16.4    10.8    14.8 " 3"
```

## Graph\_2022

```
N_response_curve_2022 <-
ggplot(yield_2022_dataframe, aes(x=Nrate, y=Yield_Mgha, color=Treatment))+
  geom_point(data=yield_2022_dataframe %>% filter(Treatment == "FR"),
    aes(x=Nrate, y=Yield_Mgha, color="FR"), size=2.5, shape="triangle") +
  geom_point(data=yield_2022_dataframe %>% filter(Treatment == "CR"),
    aes(x=Nrate, y=Yield_Mgha, color="CR"), size=2.5, shape="triangle") +
  #geom_point(data=yield_2022_dataframe, size=2.5, shape="triangle")+ #this is the mean values
  geom_point(data=yield_2022, size=1, alpha=0.4, shape="triangle")+ #this are the raw values
  scale_color_manual(values=c("#0072B2", "#FF9900"), name = "Treatment", labels = c('Continuous Rice (CR)', 'Fertilizer Rice (FR)'))
  scale_x_continuous(name=expression("N rate (kg N ha"^-1)*"), limits = c(-20, 320), breaks = seq(0, 320, 20))
  #scale_x_continuous(name=expression("N rate (kg N ha"^-1)*"), limits = c(-20, 280), breaks = c(0, 280, 320))
  scale_y_continuous(name= expression("Yield (Mg ha"^-1)*"), limits = c(0, 22), breaks = seq(0, 22, 1))
  #geom_errorbar(data=yield_2022_dataframe, aes(ymin=Yield_Mgha-Yield_Mgha_se, ymax=Yield_Mgha+Yield_Mgha_se))
  theme_classic()+
  geom_smooth(data = yield_2022, method = "lm", formula = y ~ poly(x, 2), se = FALSE)+
  #geom_vline(xintercept = c(0, 115, 155, 185, 225, 260), linetype = "twodash", color = "black") +
  theme(axis.text = element_text(size = 14), axis.title = element_text(size=16))+
  theme(legend.text = element_text(size = 16), legend.title = element_text(size = 18))+
  theme(plot.title = element_text(hjust = 0.5, size = 20, face = "bold"))+
```

```

theme(legend.position = "bottom")+
ggtitle(expression("2022"))+
annotate(
  "text",
  x = c(0),
  y = yield_2022_dataframe %>%
    filter(Treatment == "FR", Nrate == 0) %>%
    mutate(Yield_Mgha_plus_higher = Yield_Mgha + 1) %>%
    pull(Yield_Mgha_plus_higher),
  label = "*",
  size = 7,
  vjust = 0
)+
# Vertical line for CR
geom_segment(
  aes(x = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Nrate_optimal),
    xend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Nrate_optimal),
    y = 0, # Start exactly from 0 on y-axis
    yend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Yield_max)),
  linetype = "twodash", color = "#0072B2", size = 0.6
) +
# Vertical line for FR
geom_segment(
  aes(x = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Nrate_optimal),
    xend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Nrate_optimal),
    y = 0, # Start exactly from 0 on y-axis
    yend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Yield_max)),
  linetype = "twodash", color = "#FF9900", size = 0.6
) +
# Horizontal line for CR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Yield_max),
    yend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Yield_max),
    x = -20, # Start exactly from 0 on x-axis
    xend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#0072B2", size = 0.6
) +
# Horizontal line for FR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Yield_max),
    yend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Yield_max),
    x = -20, # Start exactly from 0 on x-axis
    xend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#FF9900", size = 0.6
)+
stat_regline_equation(data=yield_2022,
  aes(x=Nrate, y=Yield_Mgha, color=Treatment, group = Treatment,
    label = paste(..rr.label..)),
  formula = y ~ poly(x, 2, raw = TRUE),
  show.legend = FALSE, label.x = 0, label.y = c(16.5, 19))+
stat_regline_equation(data=yield_2022,
  aes(x=Nrate, y=Yield_Mgha, color=Treatment, group = Treatment,

```

```

        label = paste(..eq.label..),
        formula = y ~ poly(x, 2, raw = TRUE),
        show.legend = FALSE, label.x = 0, label.y = c(17.5, 20))+
geom_curve(x = top_yields_2022 %>%
  filter(Treatment == "FR") %>%
  mutate(NrateF = as.numeric(paste(NrateF))) %>%
  pull(NrateF),
  y = top_yields_2022 %>%
  filter(Treatment == "FR") %>%
  pull(emmean),
  xend = top_yields_2022 %>%
  filter(Treatment == "CR") %>%
  mutate(NrateF = as.numeric(paste(NrateF))) %>%
  pull(NrateF),
  yend = top_yields_2022 %>%
  filter(Treatment == "CR") %>%
  pull(emmean),
  color = 1, size=1,
  curvature = -0.2)+
annotate(
  "text",
  x = (top_yields_2022 %>%
    filter(Treatment == "FR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF)+
    top_yields_2022 %>%
    filter(Treatment == "CR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF))/2,
  y = mean(top_yields_2022 %>%
    filter(Treatment == "FR") %>%
    pull(emmean),
    top_yields_2022 %>%
    filter(Treatment == "CR") %>%
    pull(emmean)),
  label = "ns",
  size = 5,
  vjust = -2,
  hjust = 0.1 )

```

N\_response\_curve\_2022

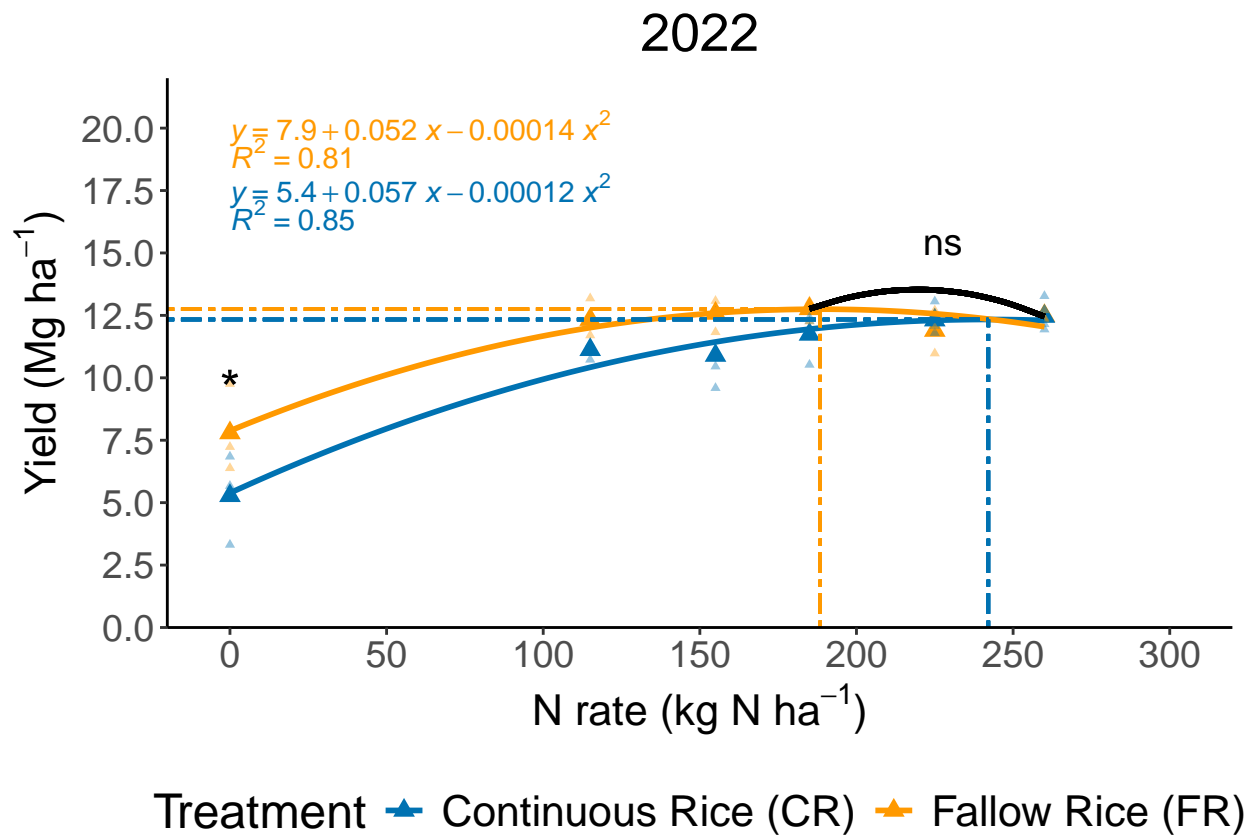
```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
```

```
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```



2023

Statistical test, comparisons by N rate and Treatment

```
model_2023 <- lmer(Yield_Mgha ~ NrateF*Treatment+(1|Blk:Treatment)+(1|Blk), data=yield_2023)
```

```
## boundary (singular) fit: see help('isSingular')
```

```
anova(model_2023)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##          Sum Sq Mean Sq NumDF DenDF F value Pr(>F)
## NrateF      31.805   6.3610     5    20  4.0251 0.01088 *
## Treatment     2.477   2.4772     1     4  1.5675 0.27878
## NrateF:Treatment 42.351   8.4702     5    20  5.3597 0.00276 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```

field_means_2023 = emmeans(model_2023, spec = 'Treatment', by = 'NrateF')
field_effects_2023 = contrast(field_means_2023, method = 'pairwise', adjust = "Tukey")

summary(field_effects_2023)

```

```

## NrateF = 0:
## contrast estimate SE df t.ratio p.value
## CR - FR -3.950 1.07 18 -3.708 0.0016
##
## NrateF = 90:
## contrast estimate SE df t.ratio p.value
## CR - FR -2.664 1.07 18 -2.501 0.0223
##
## NrateF = 120:
## contrast estimate SE df t.ratio p.value
## CR - FR -1.242 1.07 18 -1.166 0.2589
##
## NrateF = 150:
## contrast estimate SE df t.ratio p.value
## CR - FR 0.709 1.07 18 0.666 0.5139
##
## NrateF = 180:
## contrast estimate SE df t.ratio p.value
## CR - FR 2.076 1.07 18 1.948 0.0671
##
## NrateF = 210:
## contrast estimate SE df t.ratio p.value
## CR - FR 1.264 1.07 18 1.187 0.2508
##
## Degrees-of-freedom method: kenward-roger

```

```

cld(field_means_2023)

```

```

## NrateF = 0:
## Treatment emmean SE df lower.CL upper.CL .group
## CR 4.18 0.753 23.4 2.62 5.73 1
## FR 8.13 0.753 23.4 6.57 9.68 2
##
## NrateF = 90:
## Treatment emmean SE df lower.CL upper.CL .group
## CR 6.92 0.753 23.4 5.36 8.48 1
## FR 9.58 0.753 23.4 8.03 11.14 2
##
## NrateF = 120:
## Treatment emmean SE df lower.CL upper.CL .group
## CR 8.59 0.753 23.4 7.03 10.15 1
## FR 9.83 0.753 23.4 8.27 11.39 1
##
## NrateF = 150:
## Treatment emmean SE df lower.CL upper.CL .group
## FR 8.21 0.753 23.4 6.66 9.77 1
## CR 8.92 0.753 23.4 7.37 10.48 1

```

```
##
## NrateF = 180:
## Treatment emmean SE df lower.CL upper.CL .group
## FR 7.23 0.753 23.4 5.68 8.79 1
## CR 9.31 0.753 23.4 7.75 10.86 1
##
## NrateF = 210:
## Treatment emmean SE df lower.CL upper.CL .group
## FR 7.49 0.753 23.4 5.94 9.05 1
## CR 8.76 0.753 23.4 7.20 10.31 1
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
## then we cannot show them to be different.
## But we also did not show them to be the same.
```

```
emmeans(model_2023, ~ Treatment + NrateF)
```

```
## Treatment NrateF emmean SE df lower.CL upper.CL
## CR 0 4.18 0.753 23.4 2.62 5.73
## FR 0 8.13 0.753 23.4 6.57 9.68
## CR 90 6.92 0.753 23.4 5.36 8.48
## FR 90 9.58 0.753 23.4 8.03 11.14
## CR 120 8.59 0.753 23.4 7.03 10.15
## FR 120 9.83 0.753 23.4 8.27 11.39
## CR 150 8.92 0.753 23.4 7.37 10.48
## FR 150 8.21 0.753 23.4 6.66 9.77
## CR 180 9.31 0.753 23.4 7.75 10.86
## FR 180 7.23 0.753 23.4 5.68 8.79
## CR 210 8.76 0.753 23.4 7.20 10.31
## FR 210 7.49 0.753 23.4 5.94 9.05
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
```

```
cld_2023 <- cld(emmeans(model_2023, ~ Treatment + NrateF),adjust = "Sidak")
```

```
cld_2023
```

```
## Treatment NrateF emmean SE df lower.CL upper.CL .group
## CR 0 4.18 0.753 23.4 1.79 6.56 1
## CR 90 6.92 0.753 23.4 4.54 9.30 12
## FR 180 7.23 0.753 23.4 4.85 9.62 12
## FR 210 7.49 0.753 23.4 5.11 9.88 12
## FR 0 8.13 0.753 23.4 5.74 10.51 12
## FR 150 8.21 0.753 23.4 5.83 10.60 12
## CR 120 8.59 0.753 23.4 6.20 10.97 2
## CR 210 8.76 0.753 23.4 6.37 11.14 2
## CR 150 8.92 0.753 23.4 6.54 11.31 2
## CR 180 9.31 0.753 23.4 6.92 11.69 2
## FR 90 9.58 0.753 23.4 7.20 11.97 2
```

```
## FR      120      9.83 0.753 23.4      7.45      12.21      2
##
## Degrees-of-freedom method: kenward-roger
## Confidence level used: 0.95
## Conf-level adjustment: sidak method for 12 estimates
## P value adjustment: sidak method for 66 tests
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
```

```
top_yields_2023 <- cld_2023 %>%
  group_by(Treatment) %>%
  filter(emmean == max(emmean)) %>%
  ungroup()
```

## Graph\_2023

```
N_response_curve_2023 <-
ggplot(yield_2023_dataframe, aes(x=Nrate, y=Yield_Mgha, color=Treatment))+
  geom_point(data=yield_2023_dataframe, size=2.5, shape="square")+ #this is the mean values
  geom_point(data=yield_2023, size=1, alpha=0.4, shape="square")+ #this are the raw values
  scale_color_manual(values=c("#0072B2", "#FF9900"), name = "Treatment", labels = c('Continuous Rice (CR)', 'Fertilizer Response (FR)'))
  scale_x_continuous(name=expression("N rate (kg N ha"^{-1}*")"), limits = c(-20, 320), breaks = seq(0, 320, 40),
  #scale_x_continuous(name=expression("N rate (kg N ha"^{-1}*")"), limits = c(-20, 280), breaks = c(0, 40, 80, 120, 160, 200, 240, 280))
  scale_y_continuous(name= expression("Yield (Mg ha"^{-1}*")"), limits = c(0, 22), breaks = seq(0, 22, 2))
  #geom_errorbar(data=yield_2023_dataframe, aes(ymin=Yield_Mgha-Yield_Mgha_se, ymax=Yield_Mgha+Yield_Mgha_se))
  theme_classic()+
  geom_smooth(data = yield_2023, method = "lm", formula = y ~ poly(x, 2), se = FALSE)+
  #geom_vline(xintercept = c(0, 115, 155, 185, 225, 260), linetype = "twodash", color = "black") +
  theme(axis.text = element_text(size = 14), axis.title = element_text(size=16))+
  theme(legend.text = element_text(size = 16), legend.title = element_text(size = 18))+
  theme(plot.title = element_text(hjust = 0.5, size = 20, face = "bold"))+
  ggtitle(expression("2023"))+
  annotate(
    "text",
    x = c(0),
    y = yield_2023_dataframe %>%
      filter(Treatment == "FR", Nrate == 0) %>%
      mutate(Yield_Mgha_plus_higher = Yield_Mgha + 1) %>%
      pull(Yield_Mgha_plus_higher),
    label = "*",
    size = 7,
    vjust = 0
  )+
  # Vertical line for CR
  geom_segment(
    aes(x = optimal_results %>% filter(Treatment == "CR", Year == "2023") %>% pull(Nrate_optimal),
      xend = optimal_results %>% filter(Treatment == "CR", Year == "2023") %>% pull(Nrate_optimal),
      y = 0, # Start exactly from 0 on y-axis
      yend = optimal_results %>% filter(Treatment == "CR", Year == "2023") %>% pull(Yield_max)),
    linetype = "twodash", color = "#0072B2", size = 0.6
```



```

) +
# Vertical line for FR
geom_segment(
  aes(x = optimal_results %>% filter(Treatment == "FR", Year == "2023") %>% pull(Nrate_optimal),
      xend = optimal_results %>% filter(Treatment == "FR", Year == "2023") %>% pull(Nrate_optimal),
      y = 0, # Start exactly from 0 on y-axis
      yend = optimal_results %>% filter(Treatment == "FR", Year == "2023") %>% pull(Yield_max)),
  linetype = "twodash", color = "#FF9900", size = 0.6
) +

# Horizontal line for CR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "CR", Year == "2023") %>% pull(Yield_max),
      yend = optimal_results %>% filter(Treatment == "CR", Year == "2023") %>% pull(Yield_max),
      x = -20, # Start exactly from 0 on x-axis
      xend = optimal_results %>% filter(Treatment == "CR", Year == "2023") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#0072B2", size = 0.6
) +

# Horizontal line for FR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "FR", Year == "2023") %>% pull(Yield_max),
      yend = optimal_results %>% filter(Treatment == "FR", Year == "2023") %>% pull(Yield_max),
      x = -20, # Start exactly from 0 on x-axis
      xend = optimal_results %>% filter(Treatment == "FR", Year == "2023") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#FF9900", size = 0.6
)+

  geom_curve(x = top_yields_2023 %>%
    filter(Treatment == "FR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF),
    y = top_yields_2023 %>%
    filter(Treatment == "FR") %>%
    pull(emmean)+0.1,
    xend = top_yields_2023 %>%
    filter(Treatment == "CR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF),
    yend = top_yields_2023 %>%
    filter(Treatment == "CR") %>%
    pull(emmean)+0.1,
    color = 1, size=1,
    curvature = -0.2)+
stat_regline_equation(data=yield_2023,
  aes(x=Nrate, y=Yield_Mgha, color=Treatment, group = Treatment,
      label = paste(..rr.label..)),
  formula = y ~ poly(x, 2, raw = TRUE),
  show.legend = FALSE, label.x = 0, label.y = c(16.5, 19))+
stat_regline_equation(data=yield_2023,
  aes(x=Nrate, y=Yield_Mgha, color=Treatment, group = Treatment,
      label = paste(..eq.label..)),
  formula = y ~ poly(x, 2, raw = TRUE),
  show.legend = FALSE, label.x = 0, label.y = c(17.5, 20))+
annotate(

```

```

"text",
x = (top_yields_2023 %>%
      filter(Treatment == "FR") %>%
      mutate(NrateF = as.numeric(paste(NrateF))) %>%
      pull(NrateF)+
      top_yields_2023 %>%
      filter(Treatment == "CR") %>%
      mutate(NrateF = as.numeric(paste(NrateF))) %>%
      pull(NrateF))/2,
y = mean(top_yields_2023 %>%
          filter(Treatment == "FR") %>%
          pull(emmean),
          top_yields_2023 %>%
          filter(Treatment == "CR") %>%
          pull(emmean)),
label = "ns",
size = 5,
vjust = -1.3,
hjust = 0.6)

```

N\_response\_curve\_2023

```

## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.

```

```

## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.

```

```

## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.

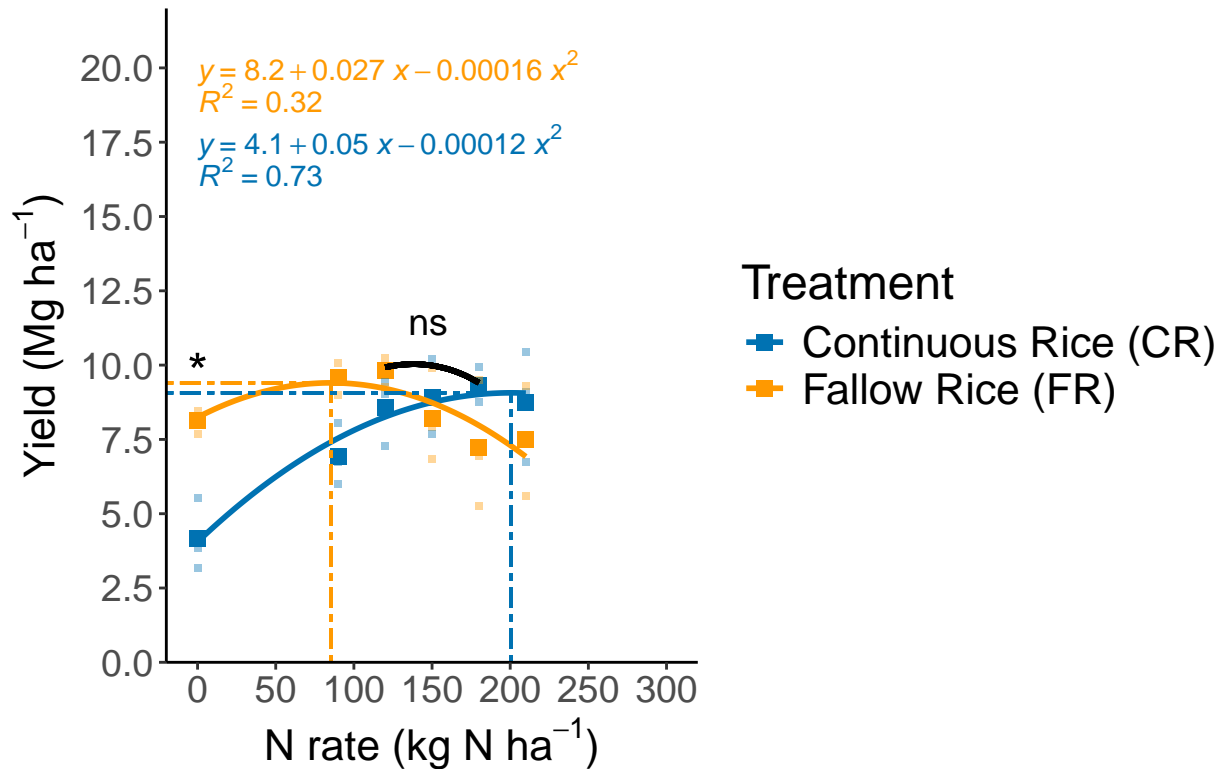
```

```

## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.

```

2023



Combine all plots

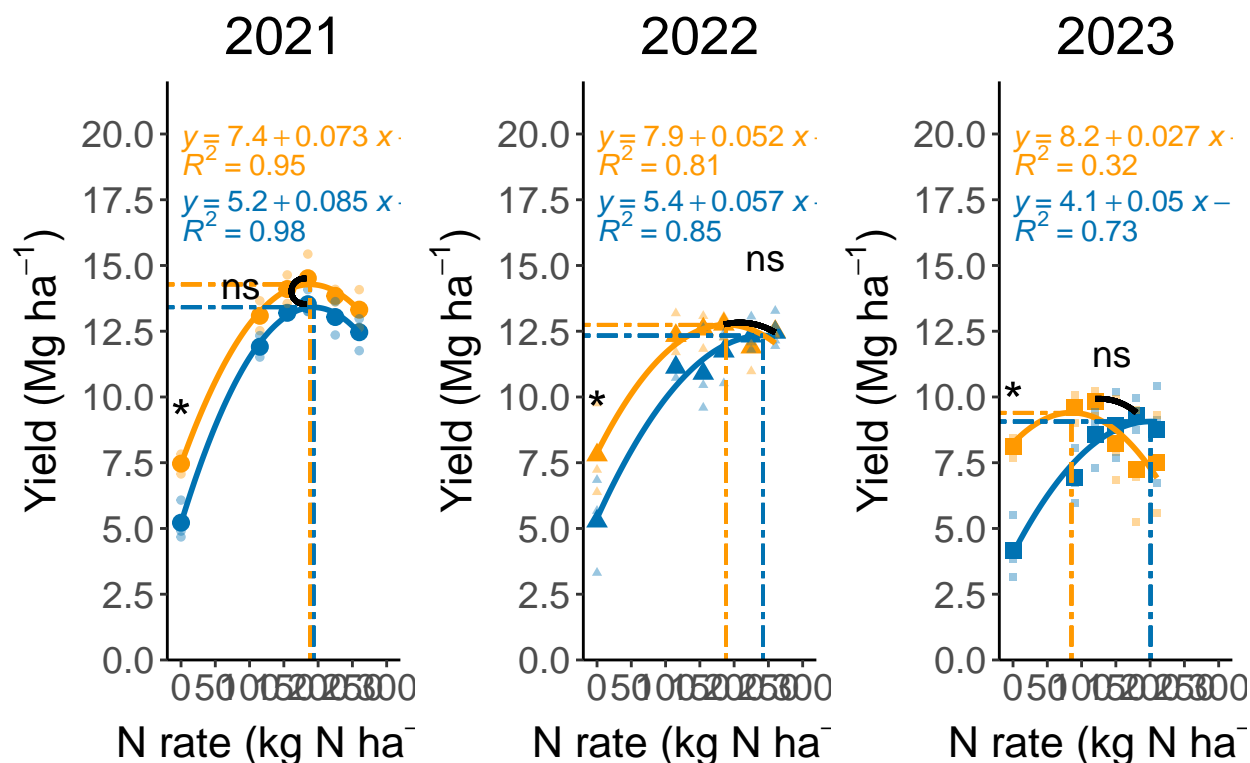
```
Yields <- ggarrange(N_response_curve_2021,
                    N_response_curve_2022,
                    N_response_curve_2023,
                    nrow = 1,
                    ncol = 3,
                    common.legend = TRUE,
                    #legend.grob = get_legend(N_response_curve_average),
                    legend = "bottom")
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.  
  
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length  
## i Please consider using 'annotate()' or provide this layer with data containing  
##   a single row.
```



Treatment — Continuous Rice (CR) — Fallow Rice (FR)

```
ggsave(filename = "Yields_no_avg.jpg", # Include the file extension here
        plot = Yields,                  # Specify the plot
        path = "C:/Users/zhang/Documents/GitHub/FallowRice_ContinuousRice_AgronomicPerformance/Figures",
        dpi = 400,
        height = 20, width = 50, units = "cm")

ggsave(filename = "2022_NResponse.jpg", # Include the file extension here
        plot = N_response_curve_2022,   # Specify the plot
        path = "C:/Users/zhang/Documents/GitHub/FallowRice_ContinuousRice_AgronomicPerformance/Figures",
        dpi = 400,
        height = 15, width = 15, units = "cm")
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

## Graphical abstract graph

```
N_response_curve_graphical_abstract <-
ggplot(yield_2022_dataframe, aes(x=Nrate, y=Yield_Mgha, color=Treatment))+
  geom_point(data=yield_2022_dataframe %>% filter(Treatment == "FR"),
    aes(x=Nrate, y=Yield_Mgha, color="FR"), size=2.5) +
  geom_point(data=yield_2022_dataframe %>% filter(Treatment == "CR"),
    aes(x=Nrate, y=Yield_Mgha, color="CR"), size=2.5) +
  #geom_point(data=yield_2022_dataframe, size=2.5, shape="triangle")+ #this is the mean values
  #geom_point(data=yield_2022, size=1, alpha=0.4, shape="triangle")+ #this are the raw values
  scale_color_manual(values=c("#0072B2", "#FF9900"), name = "Treatment", labels = c('Continuous Rice (CR',
  scale_x_continuous(name=expression("N rate (kg N ha"^-1)*")), limits = c(-20, 280), breaks = seq(0,
  scale_y_continuous(name= expression("Yield (Mg ha"^-1)*")), limits = c(0, 22), breaks = seq(0, 22, 1
  #geom_errorbar(data=yield_2022_dataframe, aes(ymin=Yield_Mgha-Yield_Mgha_se, ymax=Yield_Mgha+Yield_Mg
  theme_classic()+
  geom_smooth(data = yield_2022, method = "lm", formula = y ~ poly(x, 2), se = FALSE)+
  #geom_vline(xintercept = c(0, 115, 155, 185, 225, 260), linetype = "twodash", color = "black") +
  theme(axis.text = element_text(size = 14), axis.title = element_text(size=16))+
  theme(legend.text = element_text(size = 12), legend.title = element_text(size = 14))+
  theme(plot.title = element_text(hjust = 0.5, size = 20, face = "bold"))+
  theme(legend.position = "bottom")+
  #ggtitle(expression("Yield: 2022"))+
  annotate(
    "text",
    x = c(0),
    y = yield_2022_dataframe %>%
      filter(Treatment == "FR", Nrate == 0) %>%
      mutate(Yield_Mgha_plus_higher = Yield_Mgha + 1) %>%
      pull(Yield_Mgha_plus_higher),
    label = "*",
    size = 7,
    vjust = 0
  )+
  geom_segment(
    aes(x = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Nrate_optimal),
      xend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Nrate_optimal),
      y = 0, # Start exactly from 0 on y-axis
      yend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Yield_max)),
    linetype = "twodash", color = "#0072B2", size = 0.6
  ) +
  # Vertical line for FR
  geom_segment(
    aes(x = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Nrate_optimal),
      xend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Nrate_optimal),
      y = 0, # Start exactly from 0 on y-axis
      yend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Yield_max)),
    linetype = "twodash", color = "#FF9900", size = 0.6
```

```

) +

# Horizontal line for CR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Yield_max),
      yend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Yield_max),
      x = -20, # Start exactly from 0 on x-axis
      xend = optimal_results %>% filter(Treatment == "CR", Year == "2022") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#0072B2", size = 0.6
) +

# Horizontal line for FR
geom_segment(
  aes(y = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Yield_max),
      yend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Yield_max),
      x = -20, # Start exactly from 0 on x-axis
      xend = optimal_results %>% filter(Treatment == "FR", Year == "2022") %>% pull(Nrate_optimal)),
  linetype = "twodash", color = "#FF9900", size = 0.6
)+

  geom_curve(x = top_yields_2022 %>%
    filter(Treatment == "FR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF),
    y = top_yields_2022 %>%
    filter(Treatment == "FR") %>%
    pull(emmean),
    xend = top_yields_2022 %>%
    filter(Treatment == "CR") %>%
    mutate(NrateF = as.numeric(paste(NrateF))) %>%
    pull(NrateF),
    yend = top_yields_2022 %>%
    filter(Treatment == "CR") %>%
    pull(emmean),
    color = 1, size=1,
    curvature = -0.2)+

  annotate(
    "text",
    x = (top_yields_2022 %>%
      filter(Treatment == "FR") %>%
      mutate(NrateF = as.numeric(paste(NrateF))) %>%
      pull(NrateF)+
      top_yields_2022 %>%
      filter(Treatment == "CR") %>%
      mutate(NrateF = as.numeric(paste(NrateF))) %>%
      pull(NrateF))/2,
    y = mean(top_yields_2022 %>%
      filter(Treatment == "FR") %>%
      pull(emmean),
      top_yields_2022 %>%
      filter(Treatment == "CR") %>%
      pull(emmean)),
    label = "ns",
    size = 5,
    vjust = -2,

```

```
hjust = 0.1 )+
  theme(axis.text.y=element_blank(),
        axis.ticks.y=element_blank(),
        axis.text.x=element_blank(),
        axis.ticks.x=element_blank()
  )+
  theme(legend.title=element_blank())
```

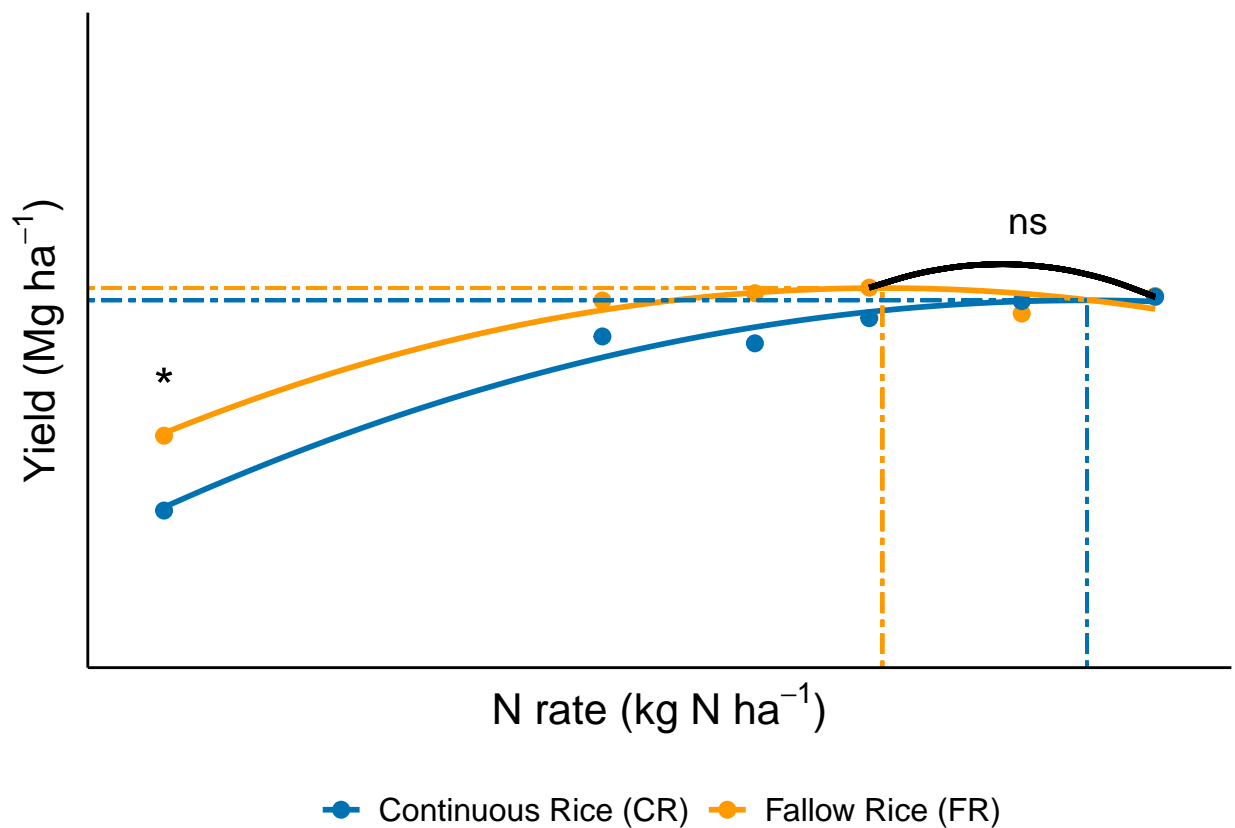
N\_response\_curve\_graphical\_abstract

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
##   a single row.
```





```
ggsave(filename = "N_response_curve_graphical_abstract.jpg", # Include the file extension here
        plot = N_response_curve_graphical_abstract,          # Specify the plot
        path = "C:/Users/zhang/Documents/GitHub/FallowRice_ContinuousRice_AgronomicPerformance/Figures",
        dpi = 800,
        height = 10, width = 10.5, units = "cm")
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(x = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```

```
## Warning in geom_segment(aes(y = optimal_results %>% filter(Treatment == : All aesthetics have length
## i Please consider using 'annotate()' or provide this layer with data containing
## a single row.
```