Soil N and Fert N Analysis

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Contents

Necessary libraries

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

Data Organisation

Read from excel

```
all_data <- read_excel("15N_N_Uptake_MaturitySummed.xlsx", sheet = 1)
```

```
## New names:
## * `` -> `...10`
```

```
str(all_data)
```

```
## tibble [60 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Sample.ID   : chr [1:60] "107 112 PI" "207 212 PI" "307 312 PI" "101 106 PI" ...
##  $ Field       : chr [1:60] "CR" "CR" "CR" "RF" ...
##  $ Blk         : chr [1:60] "1" "2" "3" "1" ...
##  $ Topdress    : chr [1:60] "N" "N" "N" "N" ...
##  $ Stage       : chr [1:60] "PI" "PI" "PI" "PI" ...
##  $ fertiliser_N: num [1:60] 50.3 38.3 43.4 48.4 37.6 ...
##  $ soil_N      : num [1:60] 52.2 48.2 58.4 69.6 60.7 ...
##  $ Days        : num [1:60] 46 46 46 46 46 46 81 81 81 81 ...
##  $ Year        : num [1:60] 2021 2021 2021 2021 2021 ...
##  $ ...10       : num [1:60] 102.4 86.5 101.9 118.1 98.4 ...
```

Clean up variables

```r
all_data <- mutate_if(all_data, is.character, as.factor)
all_data$Blk <- as.factor(all_data$Blk)
all_data$Year <- as.factor(all_data$Year)

str(all_data)
```

```
## tibble [60 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Sample.ID   : Factor w/ 60 levels "101 106 minus H",..: 8 18 28 3 13 23 9 19 29 4 ...
##  $ Field       : Factor w/ 2 levels "CR","RF": 1 1 1 2 2 2 1 1 1 2 ...
##  $ Blk         : Factor w/ 6 levels "1","2","3","4",..: 1 2 3 1 2 3 1 2 3 1 ...
##  $ Topdress    : Factor w/ 2 levels "N","Y": 1 1 1 1 1 1 2 2 2 2 ...
##  $ Stage       : Factor w/ 3 levels "Heading","Maturity",..: 3 3 3 3 3 3 1 1 1 1 ...
##  $ fertiliser_N: num [1:60] 50.3 38.3 43.4 48.4 37.6 ...
##  $ soil_N      : num [1:60] 52.2 48.2 58.4 69.6 60.7 ...
##  $ Days        : num [1:60] 46 46 46 46 46 46 81 81 81 81 ...
##  $ Year        : Factor w/ 2 levels "2021","2022": 1 1 1 1 1 1 1 1 1 1 ...
##  $ ...10       : num [1:60] 102.4 86.5 101.9 118.1 98.4 ...
```

Sub dataset for "preplant" and "topdress"

```r
preplant <- all_data %>% filter(Topdress == "N")
str(preplant)
```

```
## tibble [36 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Sample.ID   : Factor w/ 60 levels "101 106 minus H",..: 8 18 28 3 13 23 6 16 26 1 ...
##  $ Field       : Factor w/ 2 levels "CR","RF": 1 1 1 2 2 2 1 1 1 2 ...
##  $ Blk         : Factor w/ 6 levels "1","2","3","4",..: 1 2 3 1 2 3 1 2 3 1 ...
##  $ Topdress    : Factor w/ 2 levels "N","Y": 1 1 1 1 1 1 1 1 1 1 ...
##  $ Stage       : Factor w/ 3 levels "Heading","Maturity",..: 3 3 3 3 3 3 1 1 1 1 ...
##  $ fertiliser_N: num [1:36] 50.3 38.3 43.4 48.4 37.6 ...
##  $ soil_N      : num [1:36] 52.2 48.2 58.4 69.6 60.7 ...
##  $ Days        : num [1:36] 46 46 46 46 46 46 81 81 81 81 ...
##  $ Year        : Factor w/ 2 levels "2021","2022": 1 1 1 1 1 1 1 1 1 1 ...
##  $ ...10       : num [1:36] 102.4 86.5 101.9 118.1 98.4 ...
```

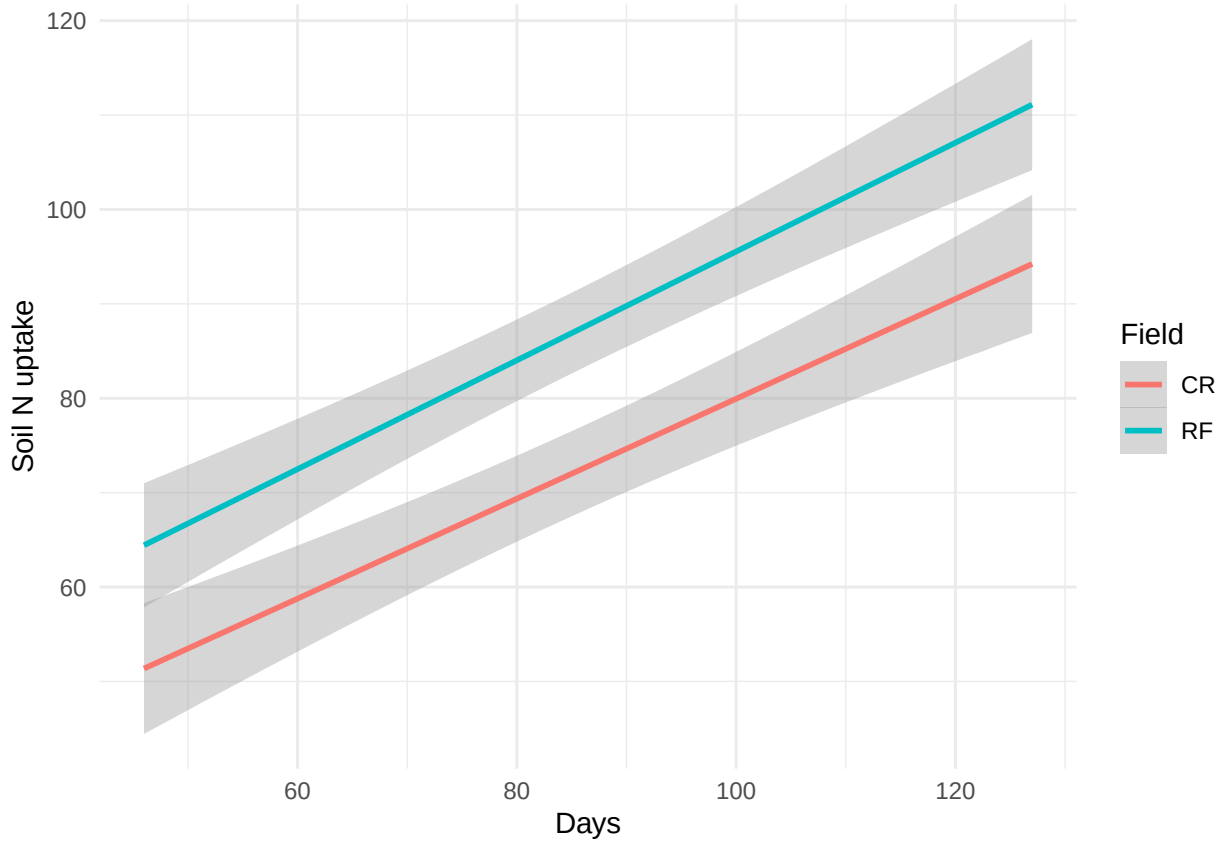
```r
topdress <- all_data %>% filter(Topdress == "Y")
str(topdress)
```

```
## tibble [24 x 10] (S3: tbl_df/tbl/data.frame)
##  $ Sample.ID   : Factor w/ 60 levels "101 106 minus H",..: 9 19 29 4 14 24 10 20 30 5 ...
##  $ Field       : Factor w/ 2 levels "CR","RF": 1 1 1 2 2 2 1 1 1 2 ...
##  $ Blk         : Factor w/ 6 levels "1","2","3","4",..: 1 2 3 1 2 3 1 2 3 1 ...
##  $ Topdress    : Factor w/ 2 levels "N","Y": 2 2 2 2 2 2 2 2 2 2 ...
##  $ Stage       : Factor w/ 3 levels "Heading","Maturity",..: 1 1 1 1 1 1 2 2 2 2 ...
##  $ fertiliser_N: num [1:24] 11.41 10.16 9.53 9.65 10.43 ...
##  $ soil_N      : num [1:24] 71.5 65.4 59.5 80.5 73.2 ...
##  $ Days        : num [1:24] 81 81 81 81 81 81 127 127 127 127 ...
##  $ Year        : Factor w/ 2 levels "2021","2022": 1 1 1 1 1 1 1 1 1 1 ...
##  $ ...10       : num [1:24] 82.9 75.6 69 90.2 83.6 ...
```

Intial visualisation

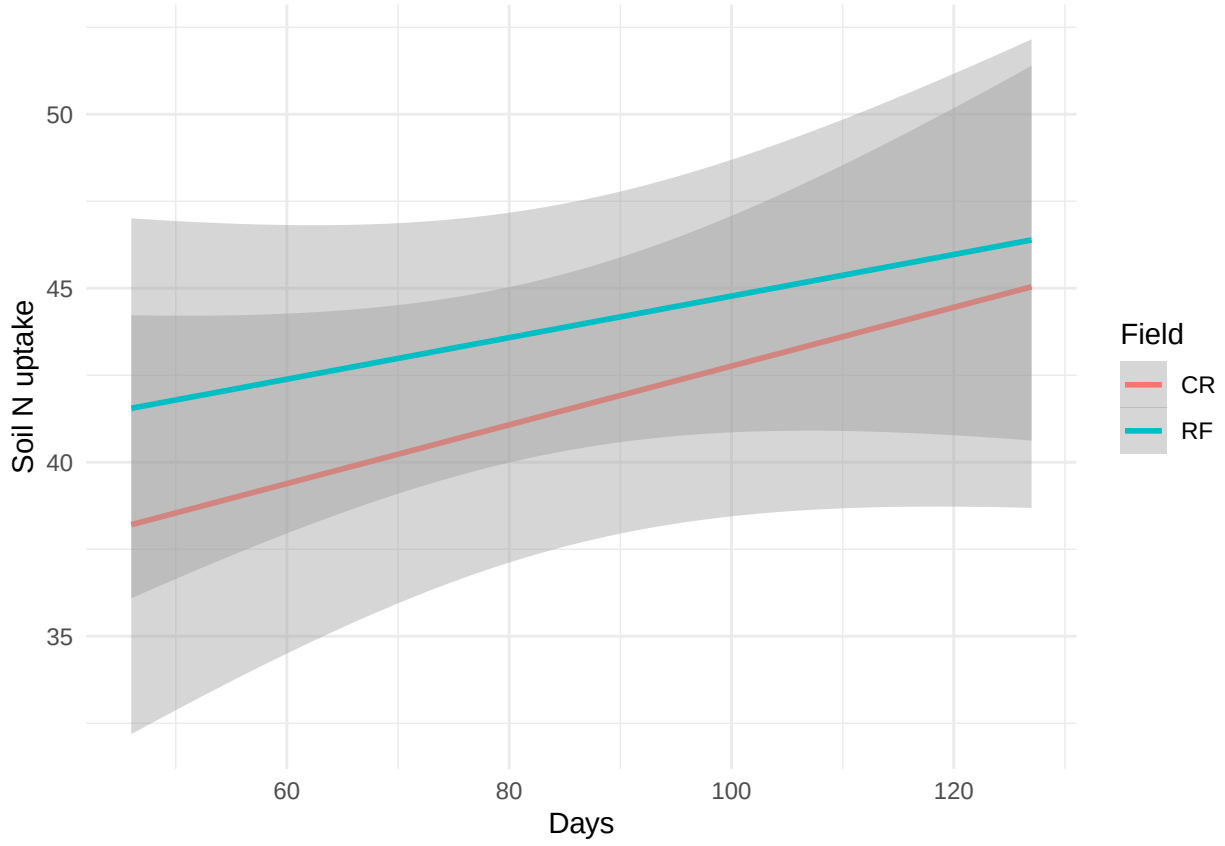
```
#preplant soil N
ggplot(preplant, aes(x = Days, y = soil_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



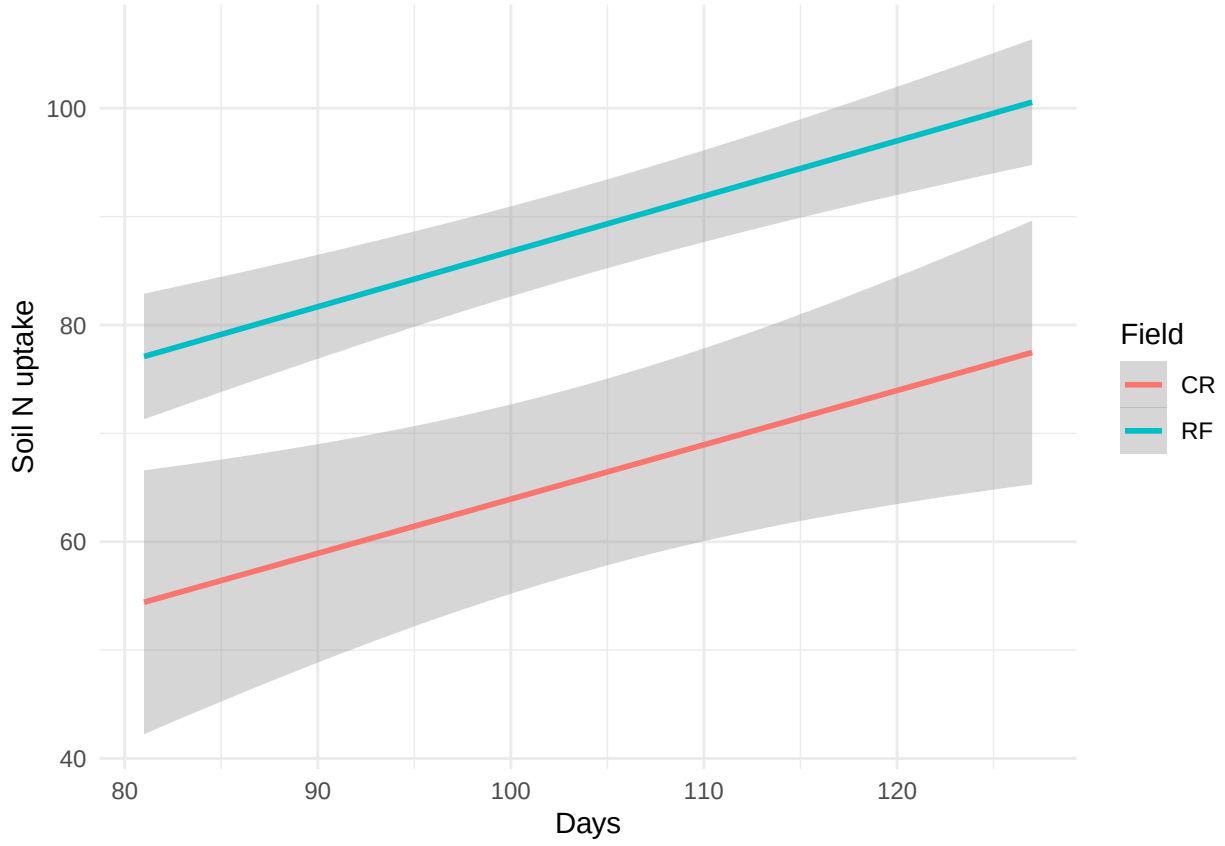

```
#preplant fert N
ggplot(preplant, aes(x = Days, y = fertiliser_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



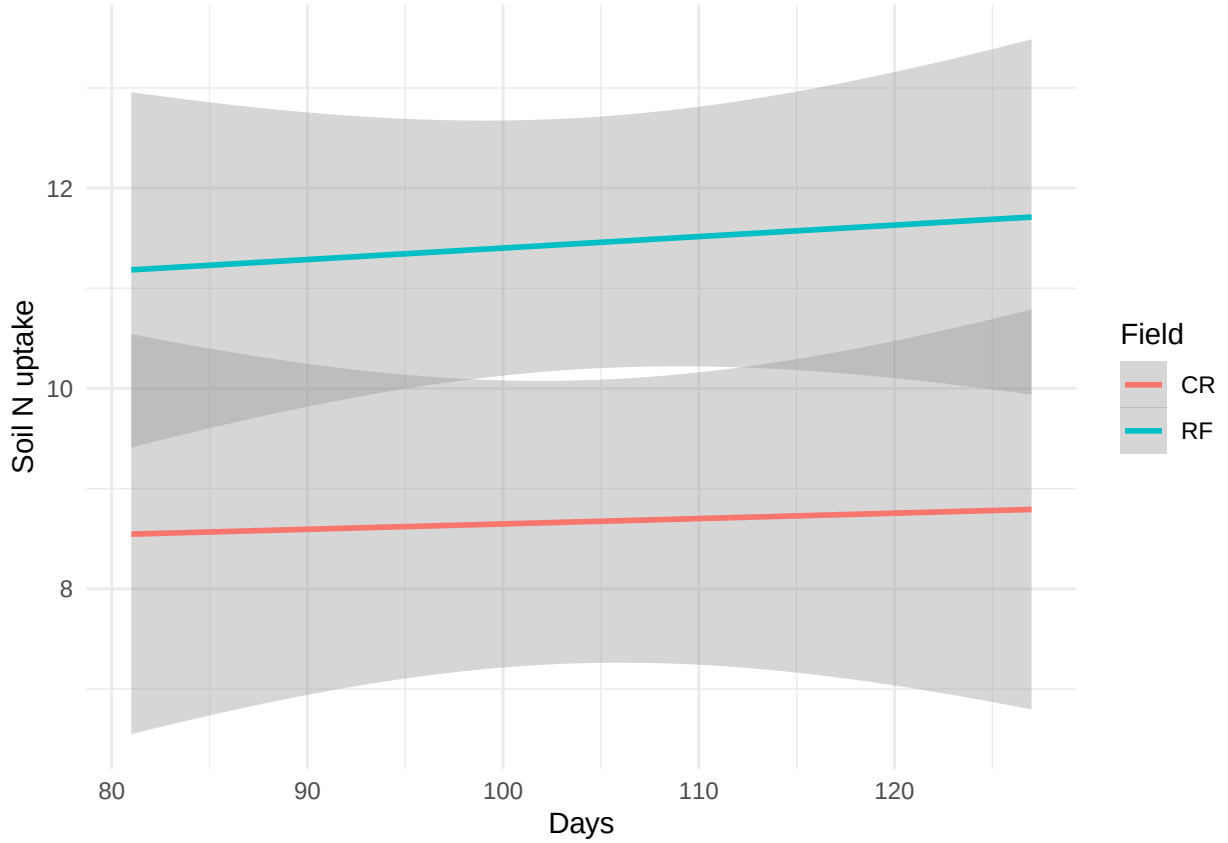

```
#topdress soil N
ggplot(topdress, aes(x = Days, y = soil_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

```
## `geom_smooth()` using formula = 'y ~ x'
```




```
#topdress fert N
ggplot(topdress, aes(x = Days, y = fertiliser_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

```
## `geom_smooth()` using formula = 'y ~ x'
```



Preplant Soil N

Model selection and testing

```
preplant_soil_N_model <- lmer(soil_N~Field*Year*Stage+(1|Blk)+(1|Blk:Field), data = preplant)
```

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

```
anova(preplant_soil_N_model)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##                   Sum Sq Mean Sq NumDF   DenDF  F value    Pr(>F)
## Field              413.6   413.6     1  7.9999  10.1633   0.01284 *
## Year                 0.0     0.0     1  7.9999   0.0006   0.98125
## Stage            12175.8  6087.9     2 16.0000 149.6038 4.407e-11 ***
## Field:Year           2.5     2.5     1  7.9999   0.0612   0.81091
## Field:Stage         22.5    11.3     2 16.0000   0.2768   0.76177
## Year:Stage          11.2     5.6     2 16.0000   0.1379   0.87223
## Field:Year:Stage   158.3    79.2     2 16.0000   1.9455   0.17526
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Strong effect of field.

```
preplant_soil_N_means = emmeans(preplant_soil_N_model,spec = 'Field',by = 'Stage')
```

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

```
preplant_soil_N_effects = contrast(preplant_soil_N_means, method = 'pairwise', adjust = "tukey")

summary(preplant_soil_N_effects)
```

```
## Stage = Heading:
##  contrast estimate   SE   df t.ratio p.value
##  CR - RF     -15.1 5.55 7.68  -2.711  0.0276
##
## Stage = Maturity:
##  contrast estimate   SE   df t.ratio p.value
##  CR - RF     -16.7 5.55 7.68  -3.012  0.0176
##
## Stage = PI:
##  contrast estimate   SE   df t.ratio p.value
##  CR - RF     -12.9 5.55 7.68  -2.316  0.0505
##
## Results are averaged over the levels of: Year
## Degrees-of-freedom method: kenward-roger
```

```
cld(preplant_soil_N_means)
```

```
## Stage = Heading:
##  Field emmean   SE   df lower.CL upper.CL .group
##  CR      71.8 3.93 14.8     63.4     80.1  1
##  RF      86.8 3.93 14.8     78.4     95.2   2
##
## Stage = Maturity:
##  Field emmean   SE   df lower.CL upper.CL .group
##  CR      93.4 3.93 14.8     85.0    101.8  1
##  RF     110.1 3.93 14.8    101.8    118.5   2
##
## Stage = PI:
##  Field emmean   SE   df lower.CL upper.CL .group
##  CR      50.3 3.93 14.8     41.9     58.7  1
##  RF      63.2 3.93 14.8     54.8     71.5  1
##
## Results are averaged over the levels of: Year
## 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.
```

Preplant soil N uptake different at all 3 sampling timepoints.

Graphing preplant soil_N mean and SE

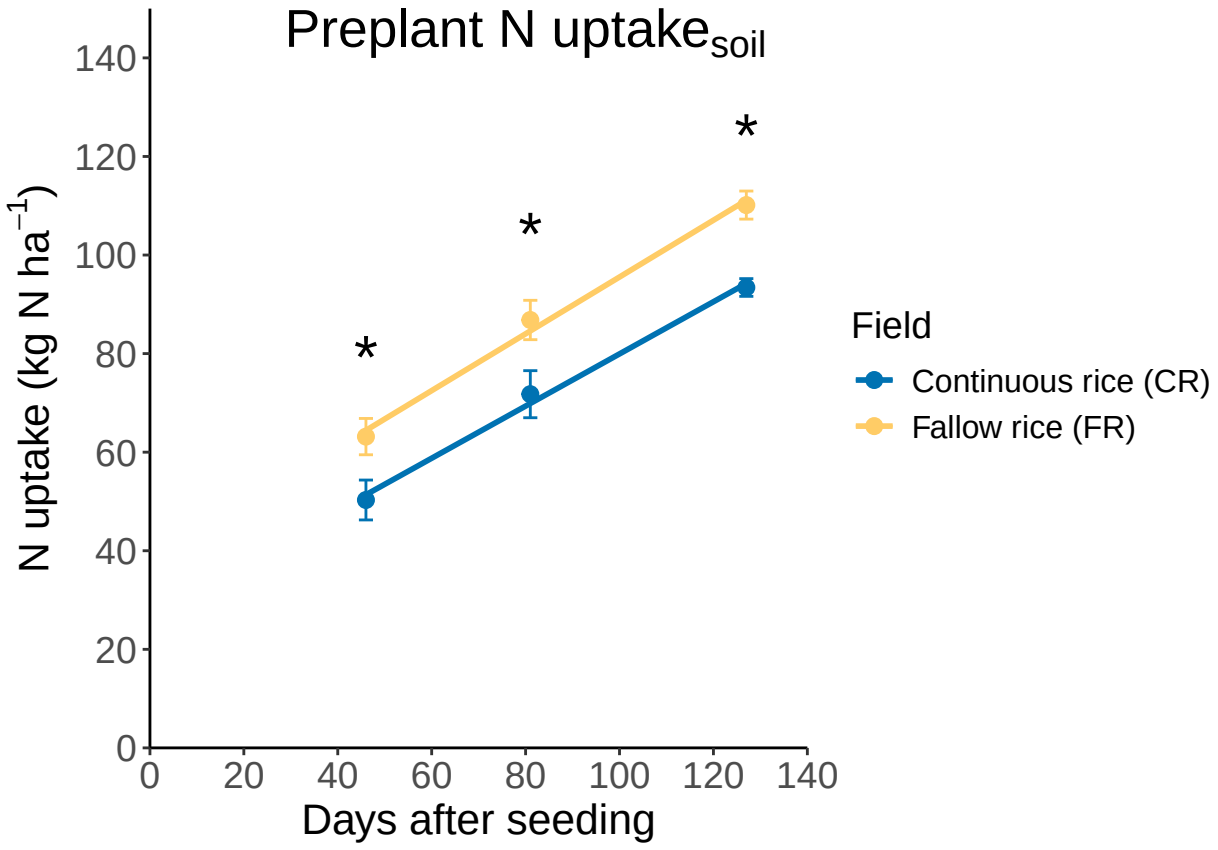
```
preplant_soilN_graphing <- preplant %>% group_by(Field, Days) %>%
  mutate(soil_N_se = sd(soil_N)/sqrt(6)) %>%
  summarise(soil_N = mean(soil_N),
            soil_N_se = mean(soil_N_se))
```

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

```
preplant_soil_N_graph <-
ggplot(preplant, aes(x=Days, y=soil_N, color=Field))+
  geom_point(data=preplant_soilN_graphing, size=2.5)+
  geom_smooth(method = lm, alpha=0)+
  scale_color_manual(values=c("#0072B2","#FFCC66"), name = "Field", labels = c("Continuous rice (CR)", "
  scale_x_continuous(name="Days after seeding", limits = c(0, 140), expand = c(0, 0), breaks = seq(0, 15
  scale_y_continuous(name=expression("N uptake (kg N ha"^{-1}*")"), limits = c(0, 150), expand = c(0, 0)
  geom_errorbar(data=preplant_soilN_graphing, aes(ymin=soil_N-soil_N_se, ymax=soil_N+soil_N_se), width=3
  #geom_vline(xintercept = c(41, 50, 78, 84, 121, 136), linetype = "dashed", color = "black") +
  theme_classic()+
  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 = 15))+
  annotate(
  "text",
  x = c(46,81, 127),  # X-axis positions for annotations
  y = c(75,100, 120),  # Y-axis positions for annotations
  label = "*",
  size = 8,
  vjust = 0  # Adjust vertical position of asterisks
)+
  annotate(
    "text",
    x = c(80),
    y = c(140),
    label = expression(paste("Preplant N uptake"[soil])),
    size = 7,
    vjust = 0
  )
preplant_soil_N_graph
```

```
## `geom_smooth()` using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```




```
ggsave(preplant_soil_N_graph, filename = "preplant_soil_N_graph.png", height = 15, width = 20, units =
```

```
## `geom_smooth()` using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```

Preplant Fert N

Model selection and testing

```
preplant_fert_N_model <- lmer(fertiliser_N~Field*Year*Stage+(1|Blk)+(1|Blk:Field), data = preplant)
```

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

```
anova(preplant_fert_N_model)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##                  Sum Sq Mean Sq NumDF DenDF F value   Pr(>F)
## Field            51.427  51.427     1    20  3.6864 0.069235 .
## Year             36.703  36.703     1     4  2.6310 0.180118
```

```
## Stage            251.851 125.926     2    20  9.0266 0.001608 **
## Field:Year       172.069 172.069     1    20 12.3343 0.002193 **
## Field:Stage       46.553  23.276     2    20  1.6685 0.213724
## Year:Stage       134.753  67.377     2    20  4.8297 0.019439 *
## Field:Year:Stage  55.821  27.910     2    20  2.0007 0.161415
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Field appears not significant

```
preplant_fert_N_means = emmeans(preplant_fert_N_model,spec = 'Field',by = 'Stage')
```

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

```
preplant_fert_N_effects = contrast(preplant_fert_N_means, method = 'pairwise', adjust = "tukey")

summary(preplant_fert_N_effects)
```

```
## Stage = Heading:
##  contrast estimate   SE df t.ratio p.value
##  CR - RF     0.511 2.16 18   0.237  0.8154
##
## Stage = Maturity:
##  contrast estimate   SE df t.ratio p.value
##  CR - RF    -2.639 2.16 18  -1.224  0.2368
##
## Stage = PI:
##  contrast estimate   SE df t.ratio p.value
##  CR - RF    -5.043 2.16 18  -2.339  0.0311
##
## Results are averaged over the levels of: Year
## Degrees-of-freedom method: kenward-roger
```

```
cld(preplant_fert_N_means)
```

```
## Stage = Heading:
##  Field emmean   SE   df lower.CL upper.CL .group
##  RF      40.5 2.53 7.93     34.7     46.4  1
##  CR      41.1 2.53 7.93     35.2     46.9  1
##
## Stage = Maturity:
##  Field emmean   SE   df lower.CL upper.CL .group
##  CR      45.1 2.53 7.93     39.2     50.9  1
##  RF      47.7 2.53 7.93     41.9     53.6  1
##
## Stage = PI:
##  Field emmean   SE   df lower.CL upper.CL .group
##  CR      38.3 2.53 7.93     32.4     44.1  1
##  RF      43.3 2.53 7.93     37.5     49.2   2
##
## Results are averaged over the levels of: Year
```

```
## 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.
```

Preplant Fert N appears to only be different at PI.

Graphing preplant fert_N mean and SE

```
preplant_fertiliser_N_graphing <- preplant %>% group_by(Field, Days) %>%
  mutate(fertiliser_N_se = sd(fertiliser_N)/sqrt(6)) %>%
  summarise(fertiliser_N = mean(fertiliser_N),
            fertiliser_N_se = mean(fertiliser_N_se))
```

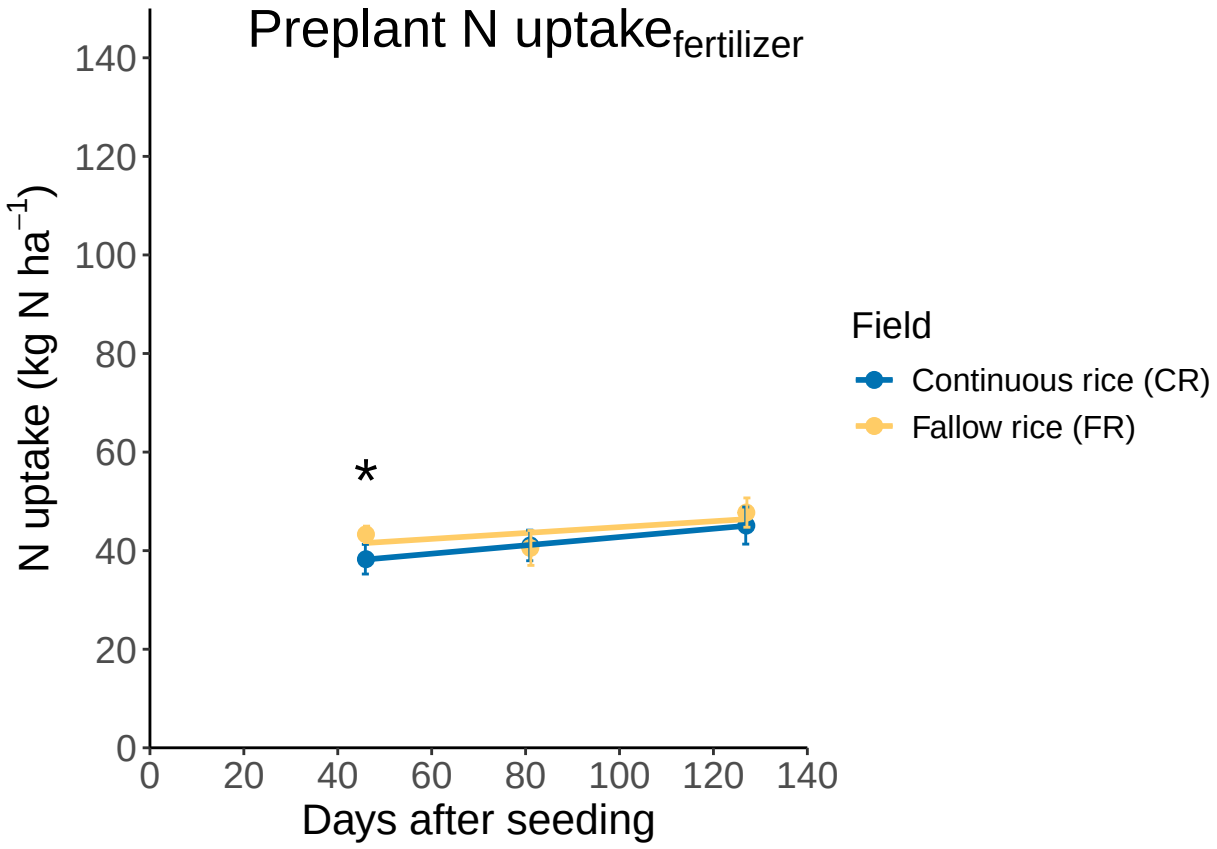
```
## `summarise()` has grouped output by 'Field'. You can override using the
## `.groups` argument.
```

```
preplant_fertiliser_N_graph <-
ggplot(preplant, aes(x=Days, y=fertiliser_N, color=Field))+
  geom_point(data=preplant_fertiliser_N_graphing, size=2.5)+
  geom_smooth(method = lm, alpha=0)+
  scale_color_manual(values=c("#0072B2","#FFCC66"), name = "Field", labels = c("Continuous rice (CR)",
  scale_x_continuous(name="Days after seeding", limits = c(0, 140), expand = c(0, 0), breaks = seq(0, 15
  scale_y_continuous(name=expression("N uptake (kg N ha"^{-1}*")"), limits = c(0, 150), expand = c(0, 0)
  geom_errorbar(data=preplant_fertiliser_N_graphing, aes(ymin=fertiliser_N-fertiliser_N_se, ymax=fertili
  #geom_vline(xintercept = c(41, 50, 78, 84, 121, 136), linetype = "dashed", color = "black") +
  theme_classic()+
  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 = 15))+
  annotate(
    "text",
    x = c(80),
    y = c(140),
    label = expression(paste("Preplant N uptake"[fertilizer])),
    size = 7,
    vjust = 0
  )+
  annotate("text",
  x = c(46),  # X-axis positions for annotations
  y = c(50),  # Y-axis positions for annotations
  label = "*",
  size = 8,
  vjust = 0  # Adjust vertical position of asterisks
)


preplant_fertiliser_N_graph
```

```
## 'geom_smooth()' using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```




```
ggsave(preplant_fertiliser_N_graph, filename = "preplant_fertiliser_N_graph.png", height = 15, width = 1
```

```
## 'geom_smooth()' using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```

Topdress Soil N

Model selection and testing

```
topdress_soil_N_model <- lmer(soil_N~Field*Year*Stage+(1|Blk)+(1|Blk:Field), data = topdress)
```

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

```r
anova(topdress_soil_N_model)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##                  Sum Sq Mean Sq NumDF DenDF  F value    Pr(>F)
## Field             403.3   403.3     1     8  24.3025   0.00115 **
## Year               29.2    29.2     1     8   1.7589   0.22137
## Stage            3245.9  3245.9     1     8 195.5819 6.625e-07 ***
## Field:Year         93.0    93.0     1     8   5.6036   0.04544 *
## Field:Stage         0.3     0.3     1     8   0.0160   0.90241
## Year:Stage         53.9    53.9     1     8   3.2450   0.10932
## Field:Year:Stage   22.7    22.7     1     8   1.3696   0.27557
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Field has strong effect on topdress soil N uptake.

```r
topdress_soil_N_means = emmeans(topdress_soil_N_model,spec = 'Field',by = 'Stage')
```

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

```r
topdress_soil_N_effects = contrast(topdress_soil_N_means, method = 'pairwise', adjust = "tukey")

summary(topdress_soil_N_effects)
```

```
## Stage = Heading:
##  contrast estimate   SE   df t.ratio p.value
##  CR - RF     -22.7 4.93 5.05  -4.598  0.0057
##
## Stage = Maturity:
##  contrast estimate   SE   df t.ratio p.value
##  CR - RF     -23.1 4.93 5.05  -4.684  0.0053
##
## Results are averaged over the levels of: Year
## Degrees-of-freedom method: kenward-roger
```

```r
cld(topdress_soil_N_means)
```

```
## Stage = Heading:
##  Field emmean   SE df lower.CL upper.CL .group
##  CR      54.4 3.49 10     46.7     62.2  1
##  RF      77.1 3.49 10     69.3     84.9   2
##
## Stage = Maturity:
##  Field emmean   SE df lower.CL upper.CL .group
##  CR      77.5 3.49 10     69.7     85.2  1
##  RF     100.6 3.49 10     92.8    108.3   2
##
## Results are averaged over the levels of: Year
## 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.
```

Graphing topdress soil_N mean and SE

```
topdress_soil_N_graphing <- topdress %>% group_by(Field, Days) %>%
  mutate(soil_N_se = sd(soil_N)/sqrt(6)) %>%
  summarise(soil_N = mean(soil_N),
            soil_N_se = mean(soil_N_se))
```

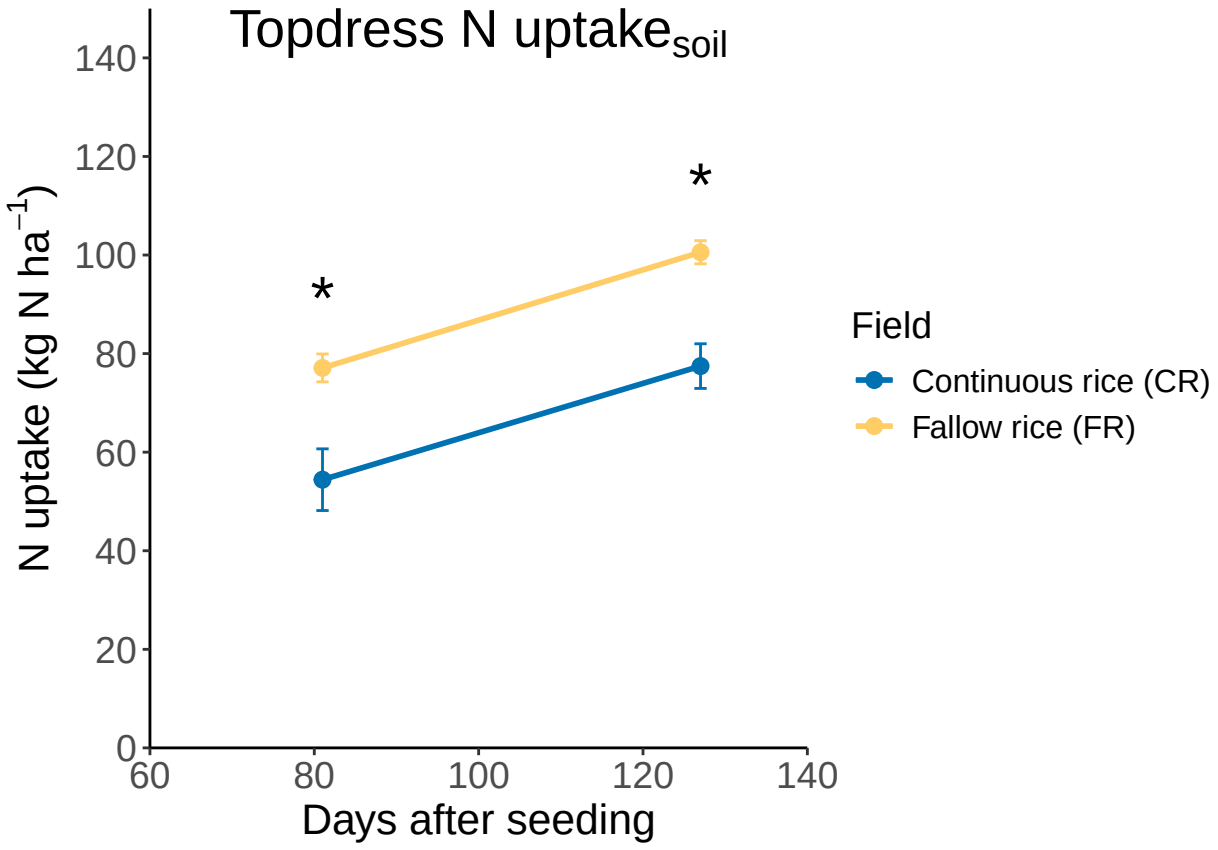
```
## `summarise()` has grouped output by 'Field'. You can override using the
## `.groups` argument.
```

```
topdress_soil_N_graph <-
ggplot(topdress, aes(x=Days, y=soil_N, color=Field))+
  geom_point(data=topdress_soil_N_graphing, size=2.5)+
  geom_smooth(method = lm, alpha=0)+
  scale_color_manual(values=c("#0072B2","#FFCC66"), name = "Field", labels = c("Continuous rice (CR)",
  scale_x_continuous(name="Days after seeding", limits = c(60, 140), expand = c(0, 0), breaks = seq(0,
  scale_y_continuous(name=expression("N uptake (kg N ha"^{-1}*")"), limits = c(0, 150), expand = c(0, 0
  geom_errorbar(data=topdress_soil_N_graphing, aes(ymin=soil_N-soil_N_se, ymax=soil_N+soil_N_se), width=
  #geom_vline(xintercept = c(78, 84, 121, 136), linetype = "dashed", color = "black") +
  theme_classic()+
  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 = 15))+
  annotate(
  "text",
  x = c(81, 127),  # X-axis positions for annotations
  y = c(87, 110),  # Y-axis positions for annotations
  label = "*",
  size = 8,
  vjust = 0  # Adjust vertical position of asterisks
)+
    annotate(
    "text",
    x = c(100),
    y = c(140),
    label = expression(paste("Topdress N uptake"[soil])),
    size = 7,
    vjust = 0
  )


topdress_soil_N_graph
```

```
## `geom_smooth()` using formula = 'y ~ x'

## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```




```
ggsave(topdress_soil_N_graph, filename = "topdress_soil_N_graph.png", height = 15, width = 20, units =
```

```
## `geom_smooth()` using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```

Topdress Fert N

Model selection and testing

```
topdress_fert_N_model <- lmer(fertiliser_N~Field*Year*Stage+(1|Blk)+(1|Blk:Field), data = topdress)
```

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

```
anova(topdress_fert_N_model)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##                 Sum Sq Mean Sq NumDF DenDF F value  Pr(>F)
## Field           6.4224  6.4224     1     8 10.6554 0.01145 *
## Year            0.0048  0.0048     1     8  0.0080 0.93109
```

```
## Stage            0.8978  0.8978     1     8  1.4896 0.25703
## Field:Year       6.1212  6.1212     1     8 10.1557 0.01287 *
## Field:Stage      0.1181  0.1181     1     8  0.1959 0.66979
## Year:Stage       0.4537  0.4537     1     8  0.7527 0.41088
## Field:Year:Stage 1.9880  1.9880     1     8  3.2983 0.10689
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Field appears significant for preplant fert N.

```
topdress_fert_N_means = emmeans(topdress_fert_N_model,spec = 'Field',by = 'Stage')
```

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

```
topdress_fert_N_effects = contrast(topdress_fert_N_means, method = 'pairwise', adjust = "tukey")

summary(topdress_fert_N_effects)
```

```
## Stage = Heading:
##  contrast estimate    SE   df t.ratio p.value
##  CR - RF     -2.64 0.908 5.14  -2.905  0.0326
##
## Stage = Maturity:
##  contrast estimate    SE   df t.ratio p.value
##  CR - RF     -2.92 0.908 5.14  -3.213  0.0227
##
## Results are averaged over the levels of: Year
## Degrees-of-freedom method: kenward-roger
```

```
cld(topdress_fert_N_means)
```

```
## Stage = Heading:
##  Field emmean    SE   df lower.CL upper.CL .group
##  CR      8.55 0.642 10.2     7.12     9.97  1
##  RF     11.18 0.642 10.2     9.76    12.61   2
##
## Stage = Maturity:
##  Field emmean    SE   df lower.CL upper.CL .group
##  CR      8.79 0.642 10.2     7.36    10.22  1
##  RF     11.71 0.642 10.2    10.28    13.14   2
##
## Results are averaged over the levels of: Year
## 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.
```

Preplant fert N uptake different at heading and maturity.

Graphing topdress fert_N mean and SE

```
topdress_fertiliser_N_graphing <- topdress %>% group_by(Field, Days) %>%
  mutate(fertiliser_N_se = sd(fertiliser_N)/sqrt(6)) %>%
  summarise(fertiliser_N = mean(fertiliser_N),
            fertiliser_N_se = mean(fertiliser_N_se))
```

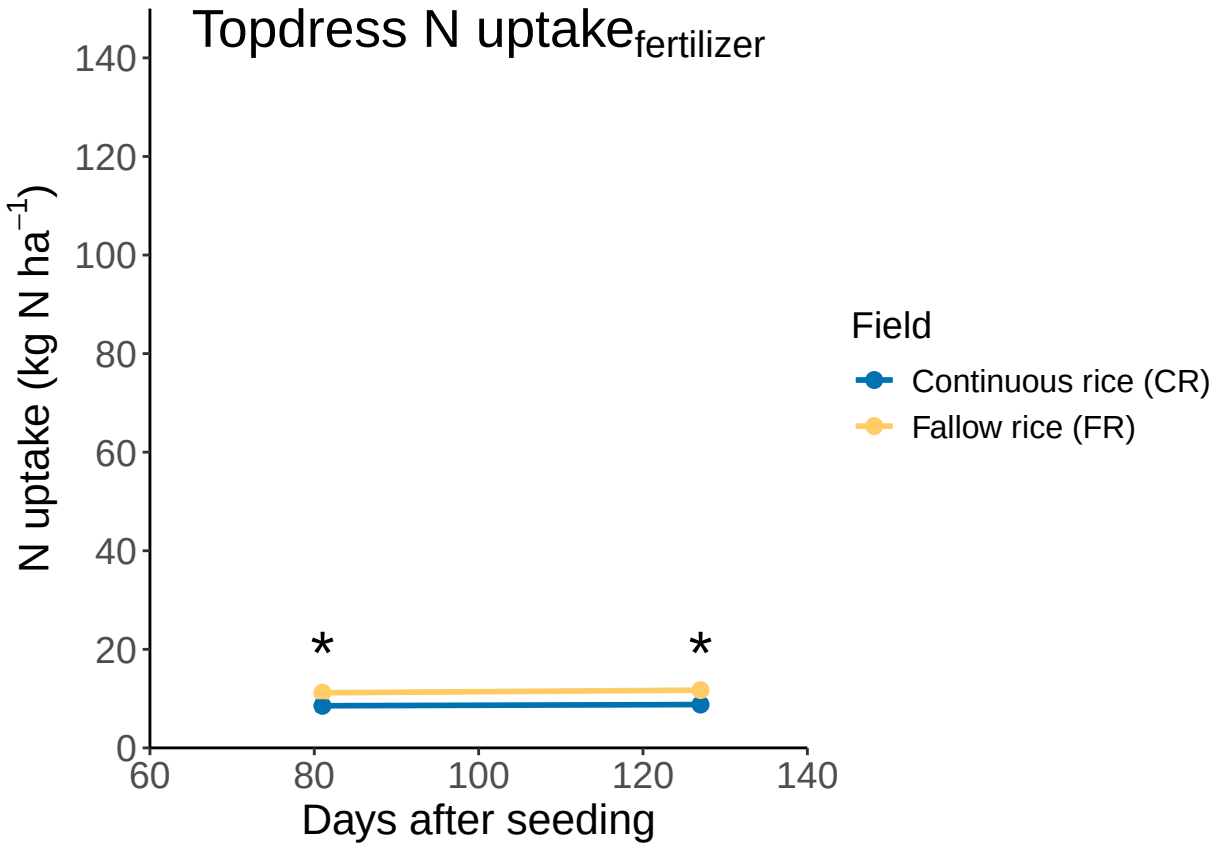
```
## `summarise()` has grouped output by 'Field'. You can override using the
## `.groups` argument.
```

```
topdress_fertiliser_N_graph <-
ggplot(topdress, aes(x=Days, y=fertiliser_N, color=Field))+
  geom_point(data=topdress_fertiliser_N_graphing, size=2.5)+
  geom_smooth(method = lm, alpha=0)+
  scale_color_manual(values=c("#0072B2","#FFCC66"), name = "Field", labels = c("Continuous rice (CR)", "
  scale_x_continuous(name="Days after seeding", limits = c(60, 140), expand = c(0, 0), breaks = seq(0, 1
  scale_y_continuous(name=expression("N uptake (kg N ha"^{-1}*")"), limits = c(0, 150), expand = c(0, 0)
  geom_errorbar(data=topdress_fertiliser_N_graphing, aes(ymin=fertiliser_N-fertiliser_N_se, ymax=fertili
  #geom_vline(xintercept = c(78, 84, 121, 136), linetype = "dashed", color = "black") +
  theme_classic()+
  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))+
  #ggtitle("Topdress fertilizer N uptake")+
  theme(plot.title = element_text(hjust = 0.5, size = 15))+
  annotate(
  "text",
  x = c(81, 127),  # X-axis positions for annotations
  y = c(15, 15),  # Y-axis positions for annotations
  label = "*",
  size = 8,
  vjust = 0  # Adjust vertical position of asterisks
)+
   annotate(
    "text",
    x = c(100),
    y = c(140),
    label = expression(paste("Topdress N uptake"[fertilizer])),
    size = 7,
    vjust = 0
  )

topdress_fertiliser_N_graph
```

```
## `geom_smooth()` using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```




```
ggsave(topdress_fertiliser_N_graph, filename = "topdress_fertiliser_N_graph.png", height = 15, width = 1
```

```
## `geom_smooth()` using formula = 'y ~ x'
```

```
## Warning in is.na(x): is.na() applied to non-(list or vector) of type
## 'expression'
```

Total N uptake

```
all_data$total_N <- all_data$fertiliser_N + all_data$soil_N

all_data %>% group_by(Topdress, Stage, Field) %>% summarise(total_N = mean(total_N))
```

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

```
## # A tibble: 10 x 4
## # Groups:   Topdress, Stage [5]
##    Topdress Stage    Field total_N
##    <fct>    <fct>    <fct>   <dbl>
##  1 N        Heading  CR      113.
```

```
##  2 N        Heading  RF      127.
##  3 N        Maturity CR      138.
##  4 N        Maturity RF      158.
##  5 N        PI       CR       88.6
##  6 N        PI       RF      106.
##  7 Y        Heading  CR       63.0
##  8 Y        Heading  RF       88.3
##  9 Y        Maturity CR       86.3
## 10 Y        Maturity RF      112.
```

```
preplant_all <- cbind(preplant_soilN_graphing,
                      preplant_fertiliser_N_graphing %>% ungroup()%>% select(-Days, -Field) %>% mutate(Topd

topdress_all <- cbind(topdress_soil_N_graphing,
                      topdress_fertiliser_N_graphing %>% ungroup()%>% select(-Days, -Field) %>% mutate(Topd

for_excel <- rbind(preplant_all, topdress_all)

write_xlsx(for_excel, "fert_soil_N_by_trt_and_topdress.xlsx")
```