

Soil N and Fert N Analysis

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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)

```

Data Organisation

Read from excel

```

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

## tibble [60 x 9] (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             : num [1:60] 1 2 3 1 2 3 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] 48.5 37 41.9 46.7 36.2 ...
##  $ soil_N          : num [1:60] 54 49.6 60 71.4 62.1 ...
##  $ Days            : num [1:60] 46 46 46 46 46 46 81 81 81 81 ...
##  $ Year            : num [1:60] 2021 2021 2021 2021 2021 2021 ...

```

Clean up variables

```

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 9] (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] 48.5 37 41.9 46.7 36.2 ...
## $ soil_N      : num [1:60] 54 49.6 60 71.4 62.1 ...
## $ 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 ...
```

Sub dataset for “preplant” and “topdress”

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

```
## tibble [36 x 9] (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] 48.5 37 41.9 46.7 36.2 ...
## $ soil_N      : num [1:36] 54 49.6 60 71.4 62.1 ...
## $ 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 ...
```

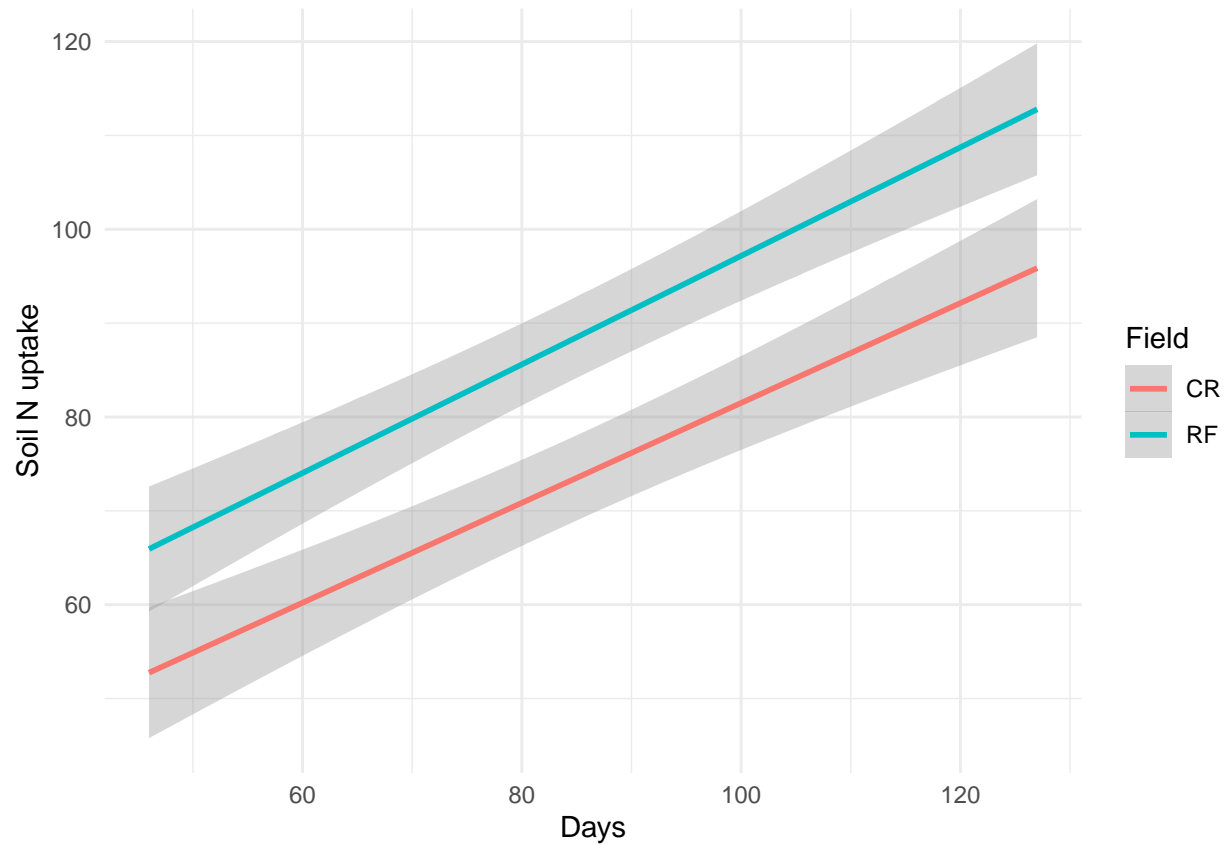
```
topdress <- all_data %>% filter(Topdress == "Y")
str(topdress)
```

```
## tibble [24 x 9] (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] 10.99 9.79 9.19 9.3 10.05 ...
## $ soil_N      : num [1:24] 71.9 65.8 59.8 80.9 73.6 ...
## $ 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 ...
```

Initial visualisation

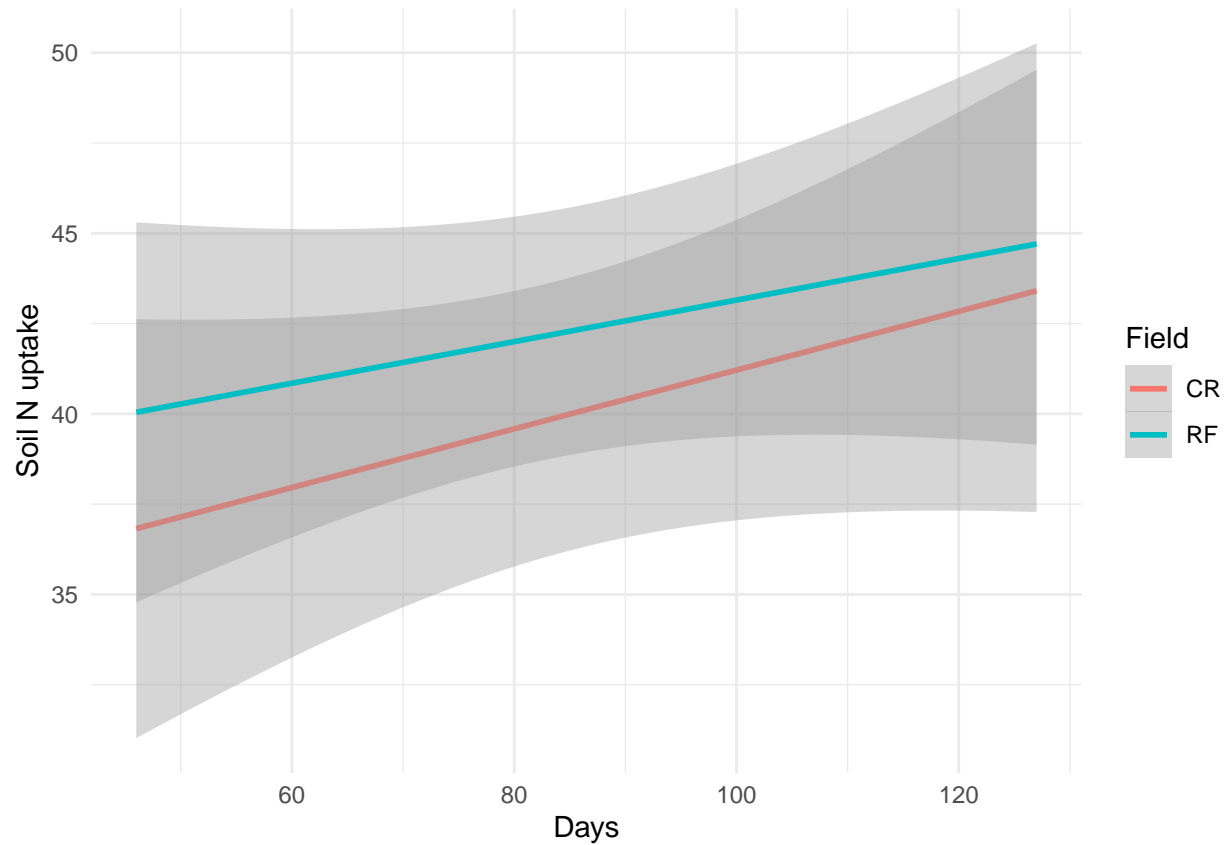
```
#preplant soil N
ggplot(preplant, aes(x = Days, y = soil_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

```
## ‘geom_smooth()’ using formula = ‘y ~ x’
```



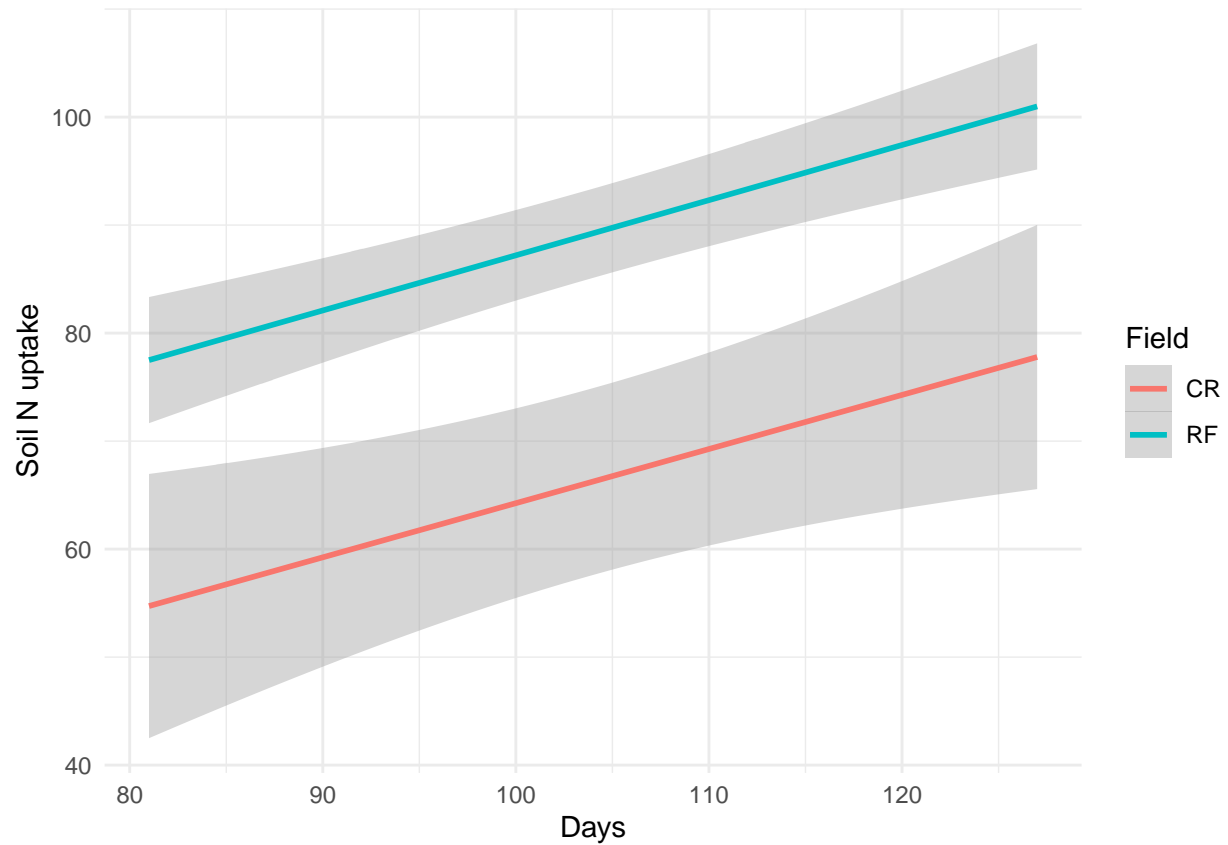
```
#preplant fert N
ggplot(preplant, aes(x = Days, y = fertiliser_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

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



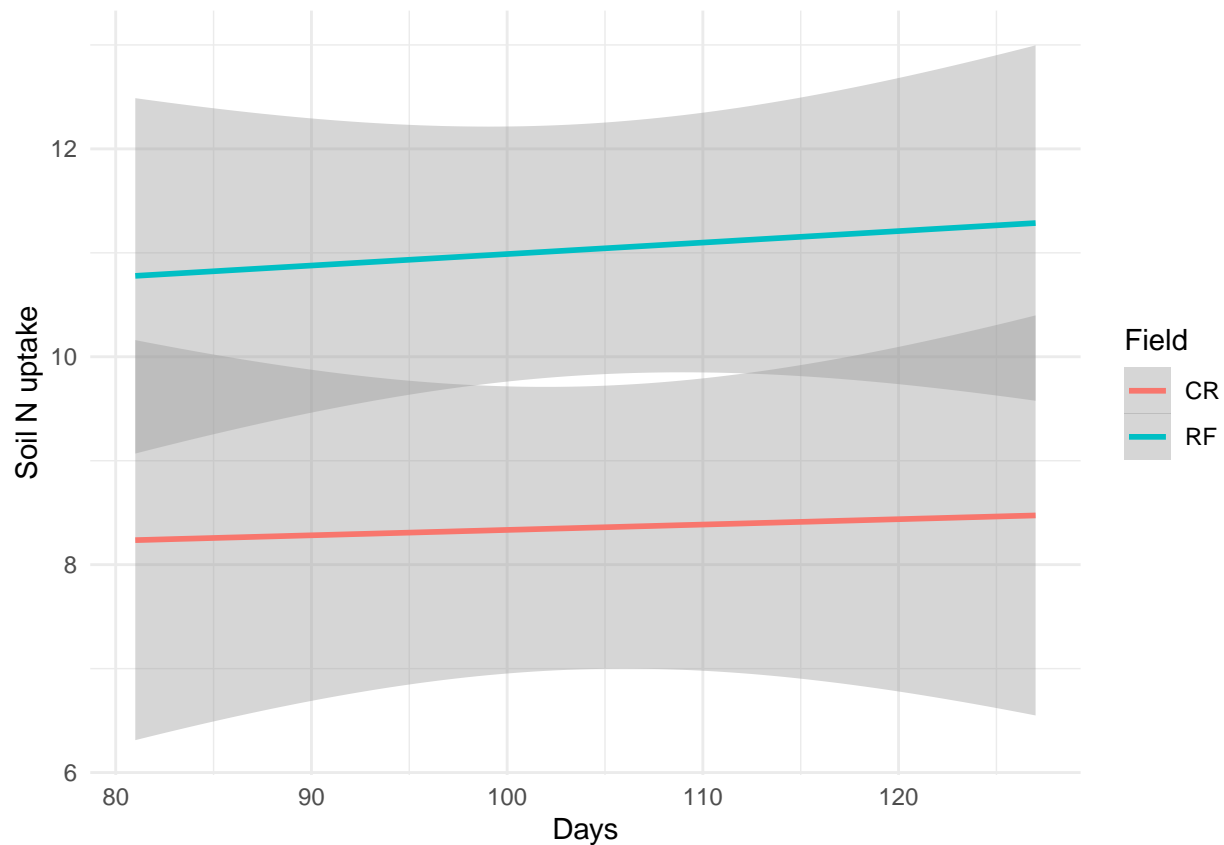
```
#topdress soil N
ggplot(topdress, aes(x = Days, y = soil_N, color = Field)) +
  geom_smooth(method = "lm") +
  labs(x = "Days", y = "Soil N uptake", color = "Field", linetype = "Year") +
  scale_linetype_manual(values = c("solid", "dashed")) +
  theme_minimal()
```

```
## '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	419.7	419.7	1	7.9999	10.1141	0.01299 *
Year	0.2	0.2	1	7.9999	0.0059	0.94061
Stage	12286.3	6143.1	2	16.0000	148.0248	4.777e-11 ***
Field:Year	3.2	3.2	1	7.9999	0.0778	0.78735
Field:Stage	21.4	10.7	2	16.0000	0.2580	0.77577
Year:Stage	13.0	6.5	2	16.0000	0.1569	0.85611
Field:Year:Stage	165.1	82.5	2	16.0000	1.9886	0.16930

```
## ---
## 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 -15.0 5.6 7.69 -2.685 0.0287
##
## Stage = Maturity:
## contrast estimate SE df t.ratio p.value
## CR - RF -16.8 5.6 7.69 -3.003 0.0178
##
## Stage = PI:
## contrast estimate SE df t.ratio p.value
## CR - RF -13.0 5.6 7.69 -2.329 0.0495
##
## 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 73.3 3.96 14.8 64.8 81.7 1
## RF 88.3 3.96 14.8 79.8 96.7 2
##
## Stage = Maturity:
## Field emmean SE df lower.CL upper.CL .group
## CR 95.0 3.96 14.8 86.6 103.5 1
## RF 111.9 3.96 14.8 103.4 120.3 2
##
## Stage = PI:
## Field emmean SE df lower.CL upper.CL .group
## CR 51.7 3.96 14.8 43.2 60.1 1
## RF 64.7 3.96 14.8 56.3 73.2 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 soil N uptake different at all 3 sampling timepoints.

Graphing preplant soil_N mean and SD

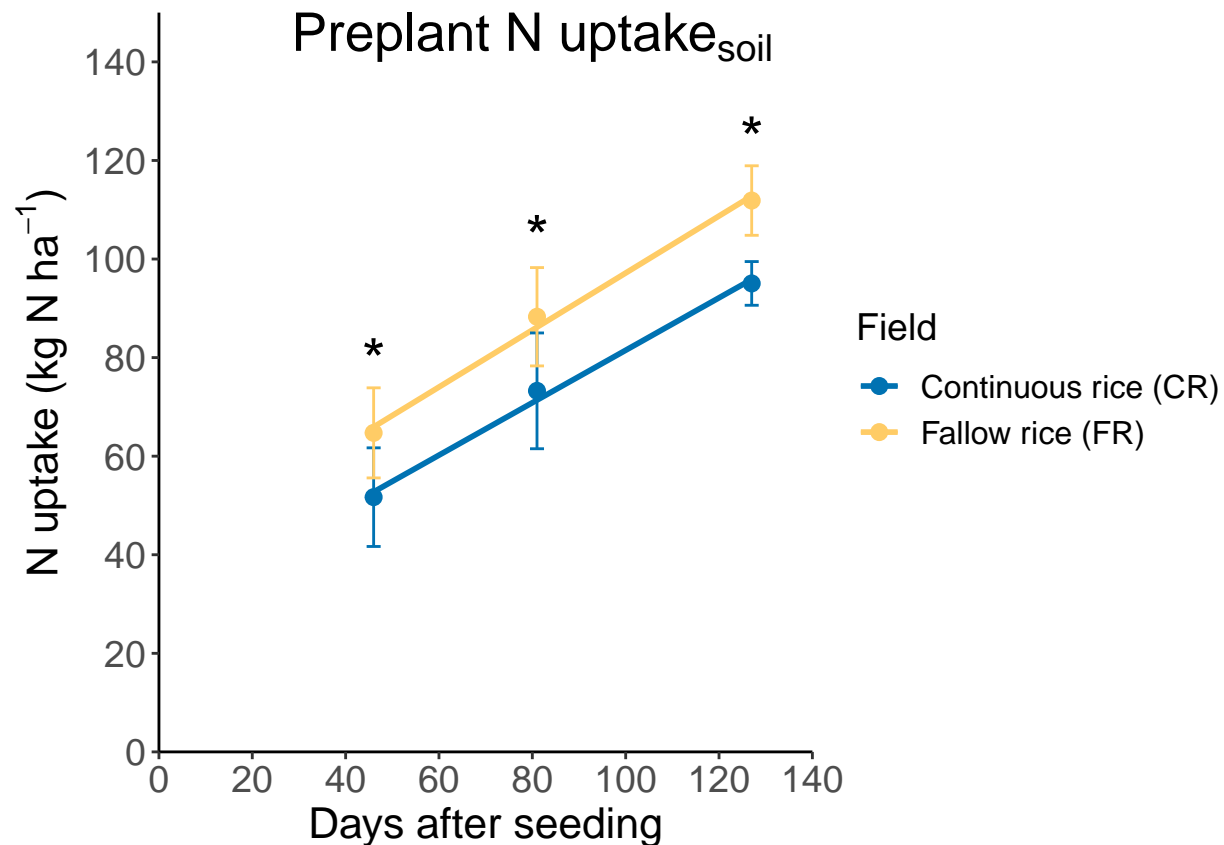
```
preplant_soilN_graphing <- preplant %>% group_by(Field, Days) %>%
  mutate(soil_N_sd = sd(soil_N)) %>%
  summarise(soil_N = mean(soil_N),
            soil_N_sd = mean(soil_N_sd))
```

```
## '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)", "Preplant N uptake (kg N ha-1)*"),
                    expand = c(0, 0), breaks = seq(0, 140, 20))+
  scale_x_continuous(name="Days after seeding", limits = c(0, 140), expand = c(0, 0), breaks = seq(0, 140, 20))+
  scale_y_continuous(name=expression("N uptake (kg N ha"^-1)*"), limits = c(0, 150), expand = c(0, 0), breaks = seq(0, 150, 20))+
  geom_errorbar(data=preplant_soilN_graphing, aes(ymin=soil_N-soil_N_sd, ymax=soil_N+soil_N_sd), width=0.5,
               #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 = "cm")
```

```
## '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         47.765   47.765     1    20  3.6864 0.069235 .
## Year          34.089   34.089     1     4  2.6310 0.180118
```

```
## Stage          233.914 116.957      2    20  9.0266 0.001608 **
## Field:Year      159.815 159.815      1    20 12.3343 0.002193 **
## Field:Stage     43.237  21.619      2    20  1.6685 0.213724
## Year:Stage      125.156  62.578      2    20  4.8297 0.019439 *
## Field:Year:Stage 51.845  25.923      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          0.492 2.08 18   0.237  0.8154
##
## Stage = Maturity:
## contrast estimate SE df t.ratio p.value
## CR - RF         -2.543 2.08 18  -1.224  0.2368
##
## Stage = PI:
## contrast estimate SE df t.ratio p.value
## CR - RF         -4.860 2.08 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      39.1 2.44 7.93    33.4    44.7  1
## CR      39.6 2.44 7.93    33.9    45.2  1
##
## Stage = Maturity:
## Field emmean SE df lower.CL upper.CL .group
## CR      43.5 2.44 7.93    37.8    49.1  1
## RF      46.0 2.44 7.93    40.4    51.6  1
##
## Stage = PI:
## Field emmean SE df lower.CL upper.CL .group
## CR      36.9 2.44 7.93    31.2    42.5  1
## RF      41.7 2.44 7.93    36.1    47.4  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 SD

```
preplant_fertiliser_N_graphing <- preplant %>% group_by(Field, Days) %>%
  mutate(fertiliser_N_sd = sd(fertiliser_N)) %>%
  summarise(fertiliser_N = mean(fertiliser_N),
            fertiliser_N_sd = mean(fertiliser_N_sd))
```

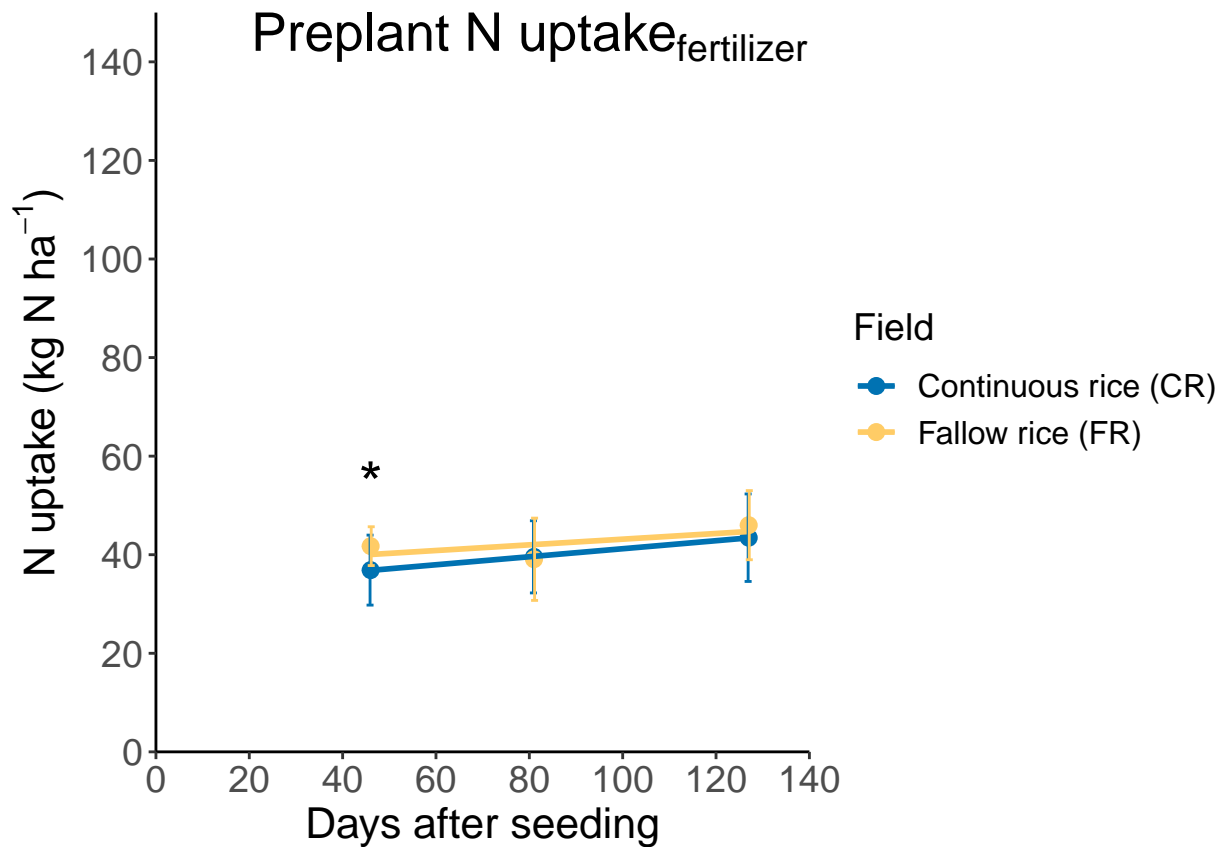
```
## 'summarise()' has grouped output by 'Field'. You can override using the
## '.groups' argument.
```

```
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)",
                                                                              "Preplant fertilizer (PF)")),
  scale_x_continuous(name="Days after seeding", limits = c(0, 140), expand = c(0, 0), breaks = seq(0, 140, 20)),
  scale_y_continuous(name=expression("N uptake (kg N ha"^{-1}*")"), limits = c(0, 150), expand = c(0, 0), breaks = seq(0, 150, 20)),
  geom_errorbar(data=preplant_fertiliser_N_graphing, aes(ymin=fertiliser_N-fertiliser_N_sd, ymax=fertiliser_N+fertiliser_N_sd)),
  #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 = 15)
```

```
## '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)
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          403.5   403.5    1    8  24.2818  0.001153 **
## Year           29.0    29.0    1    8   1.7436  0.223204
## Stage          3249.8  3249.8    1    8 195.5603 6.628e-07 ***
## Field:Year      93.9    93.9    1    8   5.6497  0.044762 *
## Field:Stage      0.3     0.3    1    8   0.0168  0.900132
## Year:Stage       54.2    54.2    1    8   3.2624  0.108519
## Field:Year:Stage 23.2    23.2    1    8   1.3973  0.271125
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Field has strong effect on topdress soil N uptake.

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

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

```
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         -22.8 4.95 5.04 -4.598 0.0057
##
## Stage = Maturity:
## contrast estimate SE df t.ratio p.value
## CR - RF         -23.2 4.95 5.04 -4.685 0.0053
##
## Results are averaged over the levels of: Year
## Degrees-of-freedom method: kenward-roger
```

```
cld(topdress_soil_N_means)
```

```
## Stage = Heading:
## Field emmean SE df lower.CL upper.CL .group
## CR      54.7 3.5 10      46.9      62.5 1
## RF      77.5 3.5 10      69.7      85.3 2
##
## Stage = Maturity:
## Field emmean SE df lower.CL upper.CL .group
## CR      77.8 3.5 10      70.0      85.6 1
## RF     101.0 3.5 10      93.2     108.8 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 SD

```
topdress_soil_N_graphing <- topdress %>% group_by(Field, Days) %>%
  mutate(soil_N_sd = sd(soil_N)) %>%
  summarise(soil_N = mean(soil_N),
            soil_N_sd = mean(soil_N_sd))
```

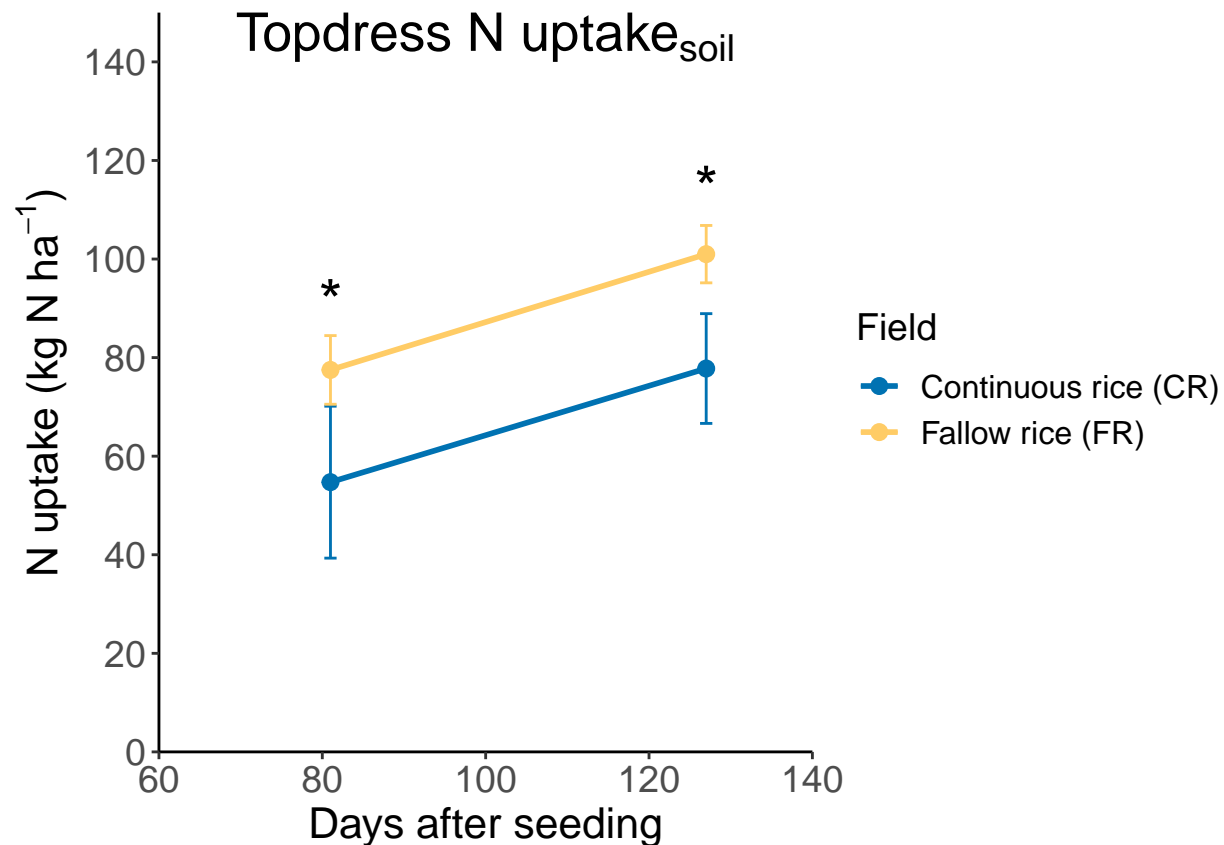
'summarise()' has grouped output by 'Field'. You can override using the
'.groups' argument.

```
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)", "Topdress rice (TR)"),
                    limits = c(60, 140), expand = c(0, 0), breaks = seq(0, 140, 20))+
  scale_x_continuous(name="Days after seeding", limits = c(60, 140), expand = c(0, 0), breaks = seq(0, 140, 20))+
  scale_y_continuous(name=expression("N uptake (kg N ha"^{-1}*")"), limits = c(0, 150), expand = c(0, 0), breaks = seq(0, 150, 20))+
  geom_errorbar(data=topdress_soil_N_graphing, aes(ymin=soil_N-soil_N_sd, ymax=soil_N+soil_N_sd), width=0.5,
               #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 = "cm")
```

```
## '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      5.9650   5.9650     1     8 10.6554 0.01145 *
## Year       0.0045   0.0045     1     8  0.0080 0.93109
```



```
## Stage          0.8339  0.8339    1    8  1.4896 0.25703
## Field:Year      5.6853  5.6853    1    8 10.1557 0.01287 *
## Field:Stage     0.1097  0.1097    1    8  0.1959 0.66979
## Year:Stage      0.4214  0.4214    1    8  0.7527 0.41088
## Field:Year:Stage 1.8464  1.8464    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          -2.54 0.875 5.14 -2.905 0.0326
##
## Stage = Maturity:
## contrast estimate SE df t.ratio p.value
## CR - RF          -2.81 0.875 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      8.24 0.619 10.2      6.86      9.61 1
## RF     10.78 0.619 10.2      9.40     12.15 2
##
## Stage = Maturity:
## Field emmean SE df lower.CL upper.CL .group
## CR      8.47 0.619 10.2      7.10      9.85 1
## RF     11.29 0.619 10.2      9.91     12.66 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 SD

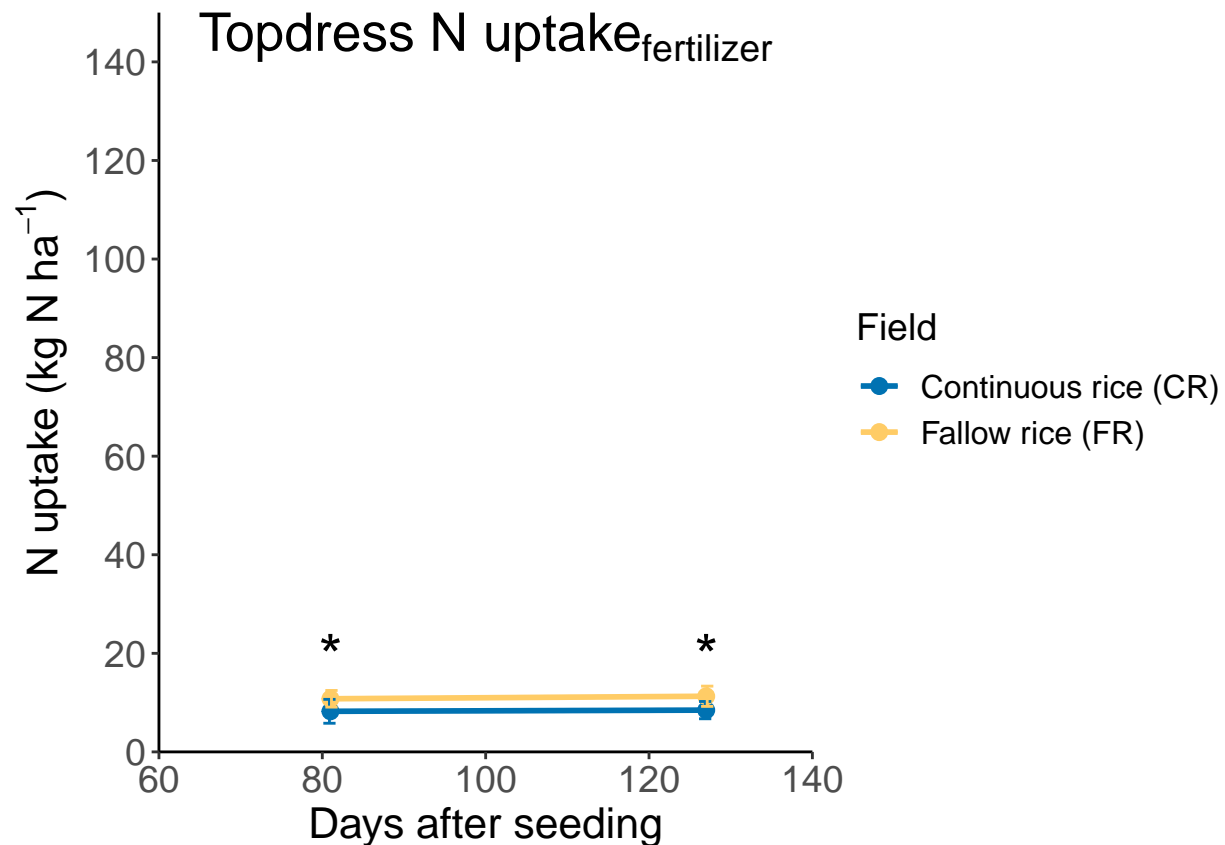
```
topdress_fertiliser_N_graphing <- topdress %>% group_by(Field, Days) %>%
  mutate(fertiliser_N_sd = sd(fertiliser_N)) %>%
  summarise(fertiliser_N = mean(fertiliser_N),
            fertiliser_N_sd = mean(fertiliser_N_sd))
```

'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)", "Topdress rice (TR)"),
                    breaks = seq(0, 140, 20), expand = c(0, 0))+
  scale_x_continuous(name="Days after seeding", limits = c(60, 140), expand = c(0, 0), breaks = seq(0, 140, 20)),
  scale_y_continuous(name=expression("N uptake (kg N ha"^-1*"")"), limits = c(0, 150), expand = c(0, 0), breaks = seq(0, 150, 20)),
  geom_errorbar(data=topdress_fertiliser_N_graphing, aes(ymin=fertiliser_N-fertiliser_N_sd, ymax=fertiliser_N+fertiliser_N_sd),
               #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 = 15)
```

```
## '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.