Coding Challenge 7 - Linear Models

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2025-04-03

#make pdf not run off the page?

```
library(knitr)
opts_chunk$set(tidy.opts=list(width.cutoff=60),tidy=TRUE)
```

1. 4 pts. Read in the data called "PlantEmergence.csv" using a relative file path and load the following libraries. tidyverse, lme4, emmeans, multcomp, and multcompView. Turn the Treatment , DaysAfterPlanting and Rep into factors using the function as.factor

STAND$Treatment <- as.factor(STAND$$Treatment) # example shown here.

```
#load in packages
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.5
## v forcats   1.0.0     v stringr   1.5.1
## v ggplot2   3.5.1     v tibble    3.2.1
## v lubridate 1.9.4     v tidyr     1.3.1
## v purrr     1.0.2
## -- Conflicts ---------------------------------------- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(lme4)
```

```
## Loading required package: Matrix
##
## Attaching package: 'Matrix'
##
## The following objects are masked from 'package:tidyr':
##
##     expand, pack, unpack
```

```
library(emmeans)
```

```
## Welcome to emmeans.
## Caution: You lose important information if you filter this package's results.
## See '? untidy'
```

```
library(multcomp)
```

```
## Loading required package: mvtnorm
## Loading required package: survival
## Loading required package: TH.data
## Loading required package: MASS
##
## Attaching package: 'MASS'
##
## The following object is masked from 'package:dplyr':
##
##     select
##
##
## Attaching package: 'TH.data'
##
## The following object is masked from 'package:MASS':
##
##     geyser
```

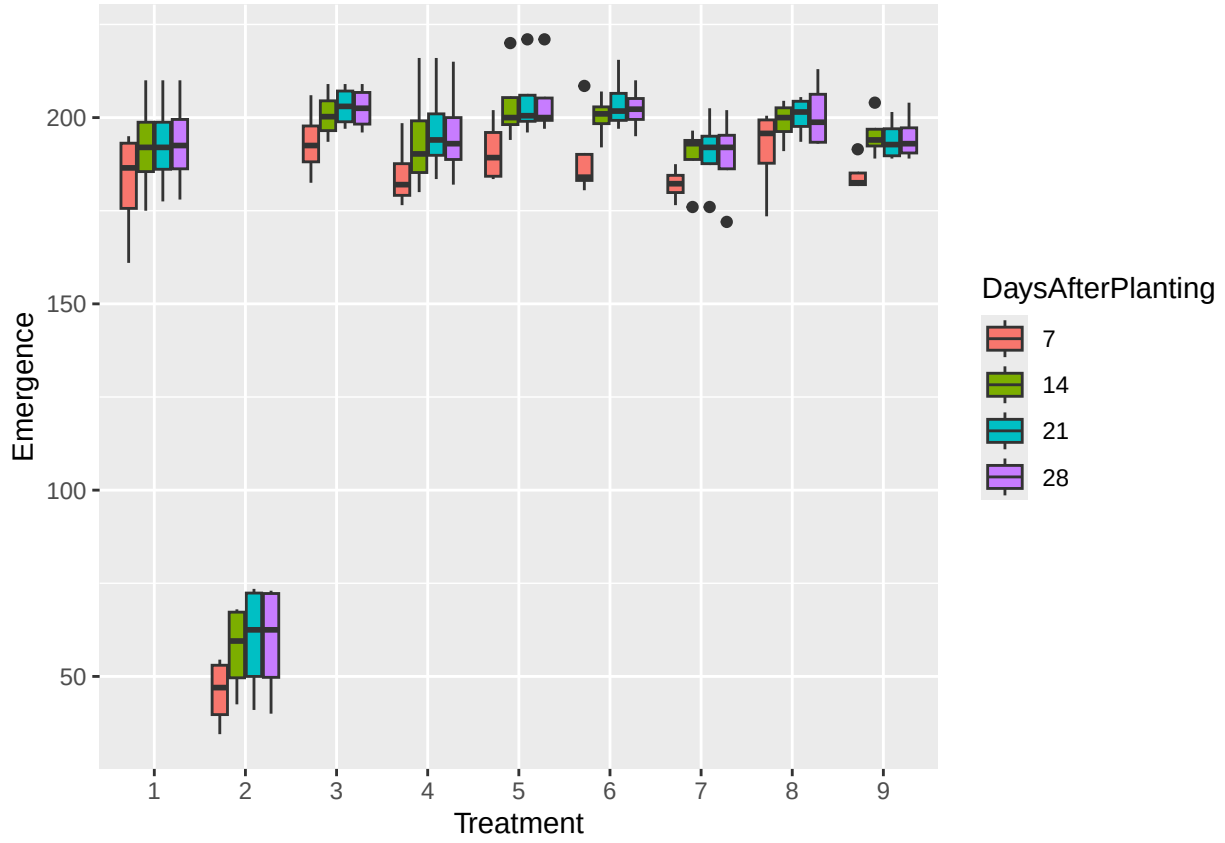
```
library(multcompView)
library(ggplot2)

#load in data
Plantdf <- read.csv("CodingChallenges/PlantEmergence.csv")
Plantdf$Treatment <- as.factor(Plantdf$Treatment)
Plantdf$DaysAfterPlanting <- as.factor(Plantdf$DaysAfterPlanting)
Plantdf$Rep <- as.factor(Plantdf$Rep)
```

2. 5 pts. Fit a linear model to predict Emergence using Treatment and

DaysAfterPlanting along with the interaction. Provide the summary of the linear model and ANOVA results.

```
#visualize the data
ggplot(data= Plantdf, aes(x= Treatment, y= Emergence, fill = DaysAfterPlanting)) +
  geom_boxplot()
```




```
#treatment within Days after planting interaction
lm <- lm(Emergence~Treatment+DaysAfterPlanting+Treatment:DaysAfterPlanting, data =Plantdf)
summary(lm)
```

```
##
## Call:
## lm(formula = Emergence ~ Treatment + DaysAfterPlanting + Treatment:DaysAfterPlanting,
##     data = Plantdf)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -21.250  -6.062  -0.875   6.750  21.875
##
## Coefficients:
##                                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)                    1.823e+02  5.324e+00  34.229   <2e-16 ***
## Treatment2                    -1.365e+02  7.530e+00 -18.128   <2e-16 ***
## Treatment3                     1.112e+01  7.530e+00   1.477    0.142
## Treatment4                     2.500e+00  7.530e+00   0.332    0.741
## Treatment5                     8.750e+00  7.530e+00   1.162    0.248
## Treatment6                     7.000e+00  7.530e+00   0.930    0.355
## Treatment7                    -1.250e-01  7.530e+00  -0.017    0.987
## Treatment8                     9.125e+00  7.530e+00   1.212    0.228
## Treatment9                     2.375e+00  7.530e+00   0.315    0.753
## DaysAfterPlanting14            1.000e+01  7.530e+00   1.328    0.187
## DaysAfterPlanting21            1.062e+01  7.530e+00   1.411    0.161
```

```
## DaysAfterPlanting28             1.100e+01  7.530e+00   1.461    0.147
## Treatment2:DaysAfterPlanting14  1.625e+00  1.065e+01   0.153    0.879
## Treatment3:DaysAfterPlanting14 -2.625e+00  1.065e+01  -0.247    0.806
## Treatment4:DaysAfterPlanting14 -6.250e-01  1.065e+01  -0.059    0.953
## Treatment5:DaysAfterPlanting14  2.500e+00  1.065e+01   0.235    0.815
## Treatment6:DaysAfterPlanting14  1.000e+00  1.065e+01   0.094    0.925
## Treatment7:DaysAfterPlanting14 -2.500e+00  1.065e+01  -0.235    0.815
## Treatment8:DaysAfterPlanting14 -2.500e+00  1.065e+01  -0.235    0.815
## Treatment9:DaysAfterPlanting14  6.250e-01  1.065e+01   0.059    0.953
## Treatment2:DaysAfterPlanting21  3.500e+00  1.065e+01   0.329    0.743
## Treatment3:DaysAfterPlanting21 -1.000e+00  1.065e+01  -0.094    0.925
## Treatment4:DaysAfterPlanting21  1.500e+00  1.065e+01   0.141    0.888
## Treatment5:DaysAfterPlanting21  2.875e+00  1.065e+01   0.270    0.788
## Treatment6:DaysAfterPlanting21  4.125e+00  1.065e+01   0.387    0.699
## Treatment7:DaysAfterPlanting21 -2.125e+00  1.065e+01  -0.200    0.842
## Treatment8:DaysAfterPlanting21 -1.500e+00  1.065e+01  -0.141    0.888
## Treatment9:DaysAfterPlanting21 -1.250e+00  1.065e+01  -0.117    0.907
## Treatment2:DaysAfterPlanting28  2.750e+00  1.065e+01   0.258    0.797
## Treatment3:DaysAfterPlanting28 -1.875e+00  1.065e+01  -0.176    0.861
## Treatment4:DaysAfterPlanting28  3.264e-13  1.065e+01   0.000    1.000
## Treatment5:DaysAfterPlanting28  2.500e+00  1.065e+01   0.235    0.815
## Treatment6:DaysAfterPlanting28  2.125e+00  1.065e+01   0.200    0.842
## Treatment7:DaysAfterPlanting28 -3.625e+00  1.065e+01  -0.340    0.734
## Treatment8:DaysAfterPlanting28 -1.500e+00  1.065e+01  -0.141    0.888
## Treatment9:DaysAfterPlanting28 -8.750e-01  1.065e+01  -0.082    0.935
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.65 on 108 degrees of freedom
## Multiple R-squared:  0.9585, Adjusted R-squared:  0.945
## F-statistic: 71.21 on 35 and 108 DF,  p-value: < 2.2e-16
```

```
anova(lm)
```

```
## Analysis of Variance Table
##
## Response: Emergence
##                              Df Sum Sq Mean Sq  F value    Pr(>F)
## Treatment                     8 279366   34921 307.9516 < 2.2e-16 ***
## DaysAfterPlanting             3   3116    1039   9.1603 1.877e-05 ***
## Treatment:DaysAfterPlanting  24    142       6   0.0522         1
## Residuals                   108  12247     113
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#is the interaction different if it's written the other way?
lm2 <- lm(Emergence~Treatment+DaysAfterPlanting+DaysAfterPlanting:Treatment, data =Plantdf)
summary(lm2)
```

```
##
## Call:
## lm(formula = Emergence ~ Treatment + DaysAfterPlanting + DaysAfterPlanting:Treatment,
##     data = Plantdf)
```

```
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -21.250  -6.062  -0.875   6.750  21.875
##
## Coefficients:
##                                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)                     1.823e+02  5.324e+00  34.229   <2e-16 ***
## Treatment2                     -1.365e+02  7.530e+00 -18.128   <2e-16 ***
## Treatment3                      1.112e+01  7.530e+00   1.477    0.142
## Treatment4                      2.500e+00  7.530e+00   0.332    0.741
## Treatment5                      8.750e+00  7.530e+00   1.162    0.248
## Treatment6                      7.000e+00  7.530e+00   0.930    0.355
## Treatment7                     -1.250e-01  7.530e+00  -0.017    0.987
## Treatment8                      9.125e+00  7.530e+00   1.212    0.228
## Treatment9                      2.375e+00  7.530e+00   0.315    0.753
## DaysAfterPlanting14             1.000e+01  7.530e+00   1.328    0.187
## DaysAfterPlanting21             1.062e+01  7.530e+00   1.411    0.161
## DaysAfterPlanting28             1.100e+01  7.530e+00   1.461    0.147
## Treatment2:DaysAfterPlanting14  1.625e+00  1.065e+01   0.153    0.879
## Treatment3:DaysAfterPlanting14 -2.625e+00  1.065e+01  -0.247    0.806
## Treatment4:DaysAfterPlanting14 -6.250e-01  1.065e+01  -0.059    0.953
## Treatment5:DaysAfterPlanting14  2.500e+00  1.065e+01   0.235    0.815
## Treatment6:DaysAfterPlanting14  1.000e+00  1.065e+01   0.094    0.925
## Treatment7:DaysAfterPlanting14 -2.500e+00  1.065e+01  -0.235    0.815
## Treatment8:DaysAfterPlanting14 -2.500e+00  1.065e+01  -0.235    0.815
## Treatment9:DaysAfterPlanting14  6.250e-01  1.065e+01   0.059    0.953
## Treatment2:DaysAfterPlanting21  3.500e+00  1.065e+01   0.329    0.743
## Treatment3:DaysAfterPlanting21 -1.000e+00  1.065e+01  -0.094    0.925
## Treatment4:DaysAfterPlanting21  1.500e+00  1.065e+01   0.141    0.888
## Treatment5:DaysAfterPlanting21  2.875e+00  1.065e+01   0.270    0.788
## Treatment6:DaysAfterPlanting21  4.125e+00  1.065e+01   0.387    0.699
## Treatment7:DaysAfterPlanting21 -2.125e+00  1.065e+01  -0.200    0.842
## Treatment8:DaysAfterPlanting21 -1.500e+00  1.065e+01  -0.141    0.888
## Treatment9:DaysAfterPlanting21 -1.250e+00  1.065e+01  -0.117    0.907
## Treatment2:DaysAfterPlanting28  2.750e+00  1.065e+01   0.258    0.797
## Treatment3:DaysAfterPlanting28 -1.875e+00  1.065e+01  -0.176    0.861
## Treatment4:DaysAfterPlanting28  3.264e-13  1.065e+01   0.000    1.000
## Treatment5:DaysAfterPlanting28  2.500e+00  1.065e+01   0.235    0.815
## Treatment6:DaysAfterPlanting28  2.125e+00  1.065e+01   0.200    0.842
## Treatment7:DaysAfterPlanting28 -3.625e+00  1.065e+01  -0.340    0.734
## Treatment8:DaysAfterPlanting28 -1.500e+00  1.065e+01  -0.141    0.888
## Treatment9:DaysAfterPlanting28 -8.750e-01  1.065e+01  -0.082    0.935
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 10.65 on 108 degrees of freedom
## Multiple R-squared:  0.9585, Adjusted R-squared:  0.945
## F-statistic: 71.21 on 35 and 108 DF,  p-value: < 2.2e-16
```

```
anova(lm2)
```

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

```
## Response: Emergence
##                              Df Sum Sq Mean Sq  F value    Pr(>F)
## Treatment                     8 279366   34921 307.9516 < 2.2e-16 ***
## DaysAfterPlanting             3   3116    1039   9.1603 1.877e-05 ***
## Treatment:DaysAfterPlanting  24    142       6   0.0522         1
## Residuals                   108  12247     113
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
#no these are the same results
```

3. 5 pts. Based on the results of the linear model in question 2, do you need to fit the

interaction term? Provide a simplified linear model without the interaction term but still testing both main effects. Provide the summary and ANOVA results. Then, interpret the intercept and the coefficient for Treatment 2.

The treatment x days after planting interaction was not significant.

```
lm3 <- lm(Emergence~Treatment+DaysAfterPlanting, data =Plantdf)
summary(lm3)
```

```
##
## Call:
## lm(formula = Emergence ~ Treatment + DaysAfterPlanting, data = Plantdf)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -21.1632  -6.1536  -0.8542   6.1823  21.3958
##
## Coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)           182.163      2.797  65.136  < 2e-16 ***
## Treatment2           -134.531      3.425 -39.277  < 2e-16 ***
## Treatment3              9.750      3.425   2.847  0.00513 **
## Treatment4              2.719      3.425   0.794  0.42876
## Treatment5             10.719      3.425   3.129  0.00216 **
## Treatment6              8.812      3.425   2.573  0.01119 *
## Treatment7             -2.188      3.425  -0.639  0.52416
## Treatment8              7.750      3.425   2.263  0.02529 *
## Treatment9              2.000      3.425   0.584  0.56028
## DaysAfterPlanting14     9.722      2.283   4.258 3.89e-05 ***
## DaysAfterPlanting21    11.306      2.283   4.951 2.21e-06 ***
## DaysAfterPlanting28    10.944      2.283   4.793 4.36e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9.688 on 132 degrees of freedom
## Multiple R-squared:  0.958,  Adjusted R-squared:  0.9545
## F-statistic: 273.6 on 11 and 132 DF,  p-value: < 2.2e-16
```

```
anova(lm3)
```

```
## Analysis of Variance Table
##
## Response: Emergence
##                     Df Sum Sq Mean Sq F value    Pr(>F)
## Treatment            8 279366   34921 372.070 < 2.2e-16 ***
## DaysAfterPlanting    3   3116    1039  11.068 1.575e-06 ***
## Residuals          132  12389      94
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The intercept is the least squared mean emergence of treatment one at 7 days (182.163). The coeffecient is the difference in treatment 2 mean emergence from the reference.

4. 5 pts. Calculate the least square means for Treatment using the emmeans package and

perform a Tukey separation with the compact letter display using the cld function. Interpret the results.

```
lsmeans <- emmeans(lm3, ~Treatment)   #runs least squared means (means estimated by the linear model)

results_lsmeans <- cld(lsmeans, alpha = 0.05, details = TRUE) # outputs which groups are different from
# .group number shows which ones are the same and sig different from each other
results_lsmeans
```

```
## $emmeans
##  Treatment emmean   SE  df lower.CL upper.CL .group
##  2           55.6 2.42 132     50.8     60.4  1
##  7          188.0 2.42 132    183.2    192.8   2
##  1          190.2 2.42 132    185.4    194.9   23
##  9          192.2 2.42 132    187.4    196.9   23
##  4          192.9 2.42 132    188.1    197.7   23
##  8          197.9 2.42 132    193.1    202.7   23
##  6          199.0 2.42 132    194.2    203.8    3
##  3          199.9 2.42 132    195.1    204.7    3
##  5          200.9 2.42 132    196.1    205.7    3
##
## Results are averaged over the levels of: DaysAfterPlanting
## Confidence level used: 0.95
## P value adjustment: tukey method for comparing a family of 9 estimates
## significance level used: alpha = 0.05
## NOTE: If two or more means share the same grouping symbol,
##       then we cannot show them to be different.
##       But we also did not show them to be the same.
##
## $comparisons
##  contrast               estimate   SE  df t.ratio p.value
##  Treatment7 - Treatment2  132.344 3.43 132  38.638  <.0001
##  Treatment1 - Treatment2  134.531 3.43 132  39.277  <.0001
##  Treatment1 - Treatment7    2.188 3.43 132   0.639  0.9993
```

```
##  Treatment9 - Treatment2  136.531 3.43 132  39.861  <.0001
##  Treatment9 - Treatment7    4.188 3.43 132   1.223  0.9502
##  Treatment9 - Treatment1    2.000 3.43 132   0.584  0.9997
##  Treatment4 - Treatment2  137.250 3.43 132  40.071  <.0001
##  Treatment4 - Treatment7    4.906 3.43 132   1.432  0.8832
##  Treatment4 - Treatment1    2.719 3.43 132   0.794  0.9969
##  Treatment4 - Treatment9    0.719 3.43 132   0.210  1.0000
##  Treatment8 - Treatment2  142.281 3.43 132  41.540  <.0001
##  Treatment8 - Treatment7    9.938 3.43 132   2.901  0.0978
##  Treatment8 - Treatment1    7.750 3.43 132   2.263  0.3724
##  Treatment8 - Treatment9    5.750 3.43 132   1.679  0.7583
##  Treatment8 - Treatment4    5.031 3.43 132   1.469  0.8678
##  Treatment6 - Treatment2  143.344 3.43 132  41.850  <.0001
##  Treatment6 - Treatment7   11.000 3.43 132   3.212  0.0425
##  Treatment6 - Treatment1    8.812 3.43 132   2.573  0.2083
##  Treatment6 - Treatment9    6.812 3.43 132   1.989  0.5538
##  Treatment6 - Treatment4    6.094 3.43 132   1.779  0.6957
##  Treatment6 - Treatment8    1.062 3.43 132   0.310  1.0000
##  Treatment3 - Treatment2  144.281 3.43 132  42.124  <.0001
##  Treatment3 - Treatment7   11.938 3.43 132   3.485  0.0187
##  Treatment3 - Treatment1    9.750 3.43 132   2.847  0.1120
##  Treatment3 - Treatment9    7.750 3.43 132   2.263  0.3724
##  Treatment3 - Treatment4    7.031 3.43 132   2.053  0.5099
##  Treatment3 - Treatment8    2.000 3.43 132   0.584  0.9997
##  Treatment3 - Treatment6    0.938 3.43 132   0.274  1.0000
##  Treatment5 - Treatment2  145.250 3.43 132  42.406  <.0001
##  Treatment5 - Treatment7   12.906 3.43 132   3.768  0.0074
##  Treatment5 - Treatment1   10.719 3.43 132   3.129  0.0535
##  Treatment5 - Treatment9    8.719 3.43 132   2.545  0.2204
##  Treatment5 - Treatment4    8.000 3.43 132   2.336  0.3288
##  Treatment5 - Treatment8    2.969 3.43 132   0.867  0.9943
##  Treatment5 - Treatment6    1.906 3.43 132   0.557  0.9998
##  Treatment5 - Treatment3    0.969 3.43 132   0.283  1.0000
##
## Results are averaged over the levels of: DaysAfterPlanting
## P value adjustment: tukey method for comparing a family of 9 estimates
```

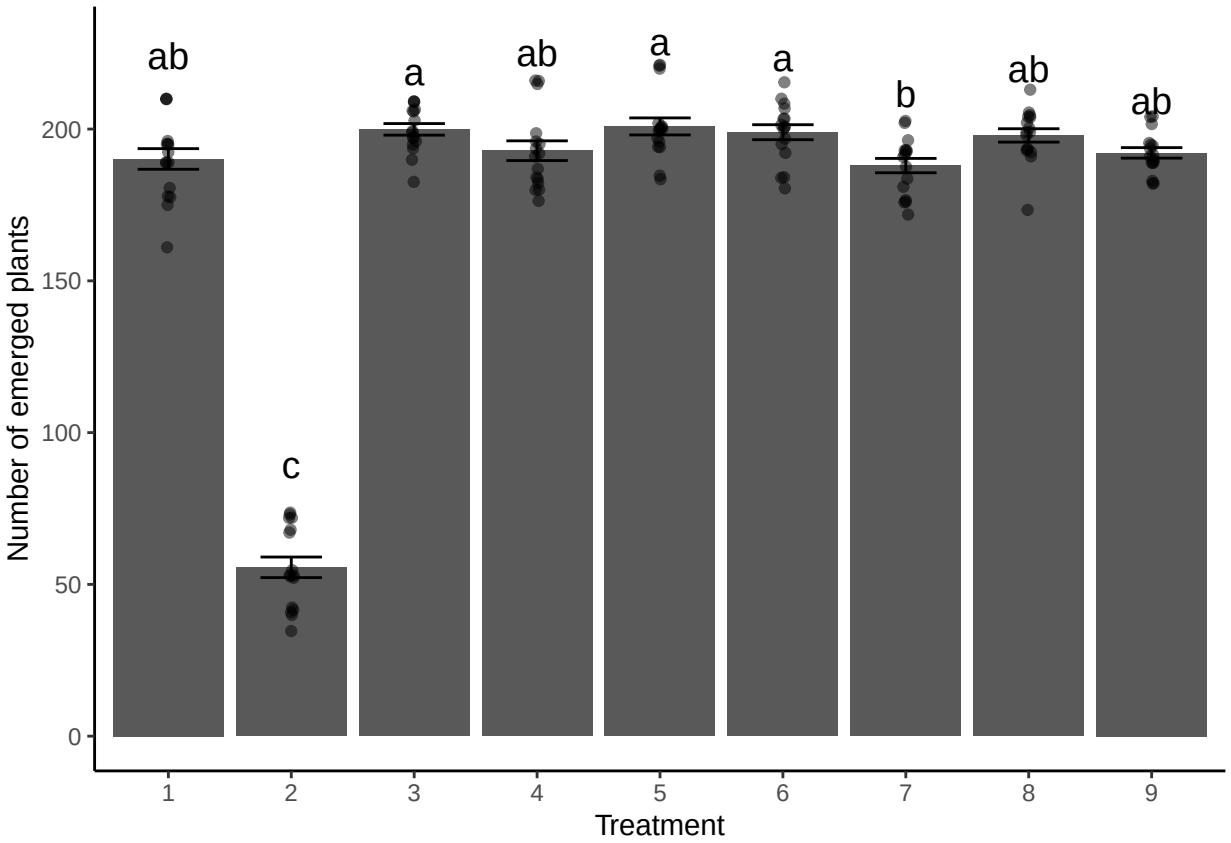
Treatment 2 was significantly lower than all other groups with a mean of 55.6 plants emerged. Treatments 6, 3, and 5 had the highest means and were significantly higher than treatments 7 and 2. Treatments 1, 9, 4, 8 were only significantly different from treatment 1

5. 4 pts. The provided function lets you dynamically add a linear model plus one factor from that model and plots a bar chart with letters denoting treatment differences. Use this model to generate the plot shown below. Explain the significance of the letters.

```
plot_cldbars_onefactor <- function(lm_model, factor) {
  data <- lm_model$model
  variables <- colnames(lm_model$model)
  dependent_var <- variables[1]
  independent_var <- variables[2:length(variables)]
```

```
  lsmeans <- emmeans(lm_model, as.formula(paste("~", factor))) # estimate
  lsmeans
  Results_lsmeans <- cld(lsmeans, alpha = 0.05, reversed = TRUE, details =
  TRUE, Letters = letters) # contrast with Tukey adjustment by default.
  # Extracting the letters for the bars
  sig.diff.letters <- data.frame(Results_lsmeans$emmeans[,1],
  str_trim(Results_lsmeans$emmeans[,7]))
  colnames(sig.diff.letters) <- c(factor, "Letters")
  # for plotting with letters from significance test
  ave_stand2 <- lm_model$model %>%
  group_by(!!sym(factor)) %>%
  dplyr::summarize(
  ave.emerge = mean(.data[[dependent_var]], na.rm = TRUE),
  se = sd(.data[[dependent_var]]) / sqrt(n())
  ) %>%
  left_join(sig.diff.letters, by = factor) %>%
  mutate(letter_position = ave.emerge + 10 * se)
  plot <- ggplot(data, aes(x = !! sym(factor), y = !! sym(dependent_var))) +
  stat_summary(fun = mean, geom = "bar") +
  stat_summary(fun.data = mean_se, geom = "errorbar", width = 0.5) +
  ylab("Number of emerged plants") +
  geom_jitter(width = 0.02, alpha = 0.5) +
  geom_text(data = ave_stand2, aes(label = Letters, y = letter_position),
  size = 5) +
  xlab(as.character(factor)) +
  theme_classic()
  return(plot)
}

plot_cldbars_onefactor(lm3, "Treatment")
```



The letters show which treatments are significantly different from each other. Treatment 2 has a unique letter, c, which means it is significantly different from all other groups. Treatments 3, 5, and 6, are significantly higher than treatments listed with only b and c, but not different from each other or those also listed with a (such as 1, 4,and 8.

6. 2 pts. Generate the gfm .md file along with a .html, .docx, or .pdf. Commit, and push the .md file to github and turn in the .html, .docx, or .pdf to Canvas. Provide me a link here to your GitHub.

Link to GitHub