

CNSeedDrop_Summary

Summary of findings:

1. Mowing significant increases drop time whereas warming significantly decreases drop time. The observed difference in the mowing treatment appears to be driven by the early mow treatment.
2. The effect of mowing is not present when the data is transformed to terminal velocity. We see that warming significantly decreases terminal velocity.
3. Seed width and seed volume show similar responses to warming and mowing. Both are decreased by mowing and warming, and the seeds that show the strongest effect are those which are both mowed and warmed (suggests interaction).
4. Plant height is significantly decreased by mowing. Warming allows early mowed plants to reach similar heights as warmed control plants. There is no significant difference between ambient/warmed late mowed plants. Non-mowed ambient plants are taller than warmed non-mowed plants.

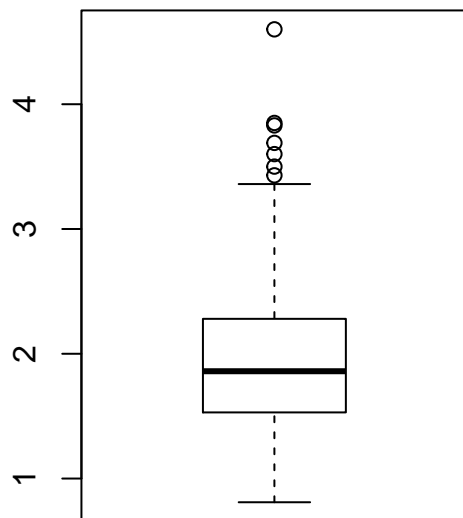
Questions:

1. Strategy for handling late mow

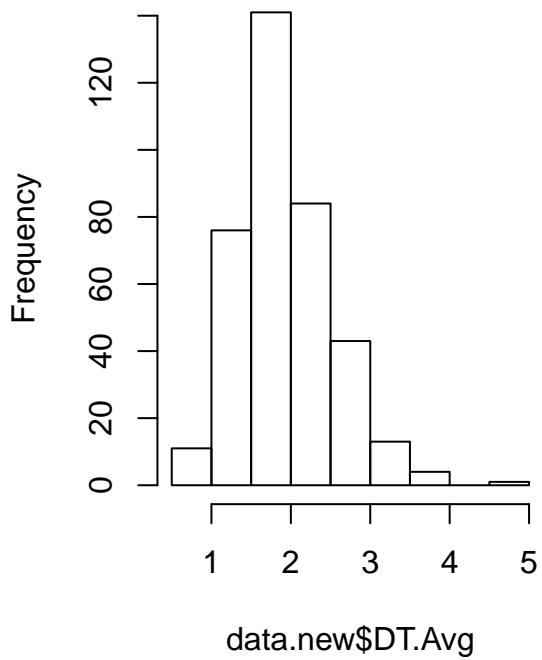
To Dos:

1. GLM

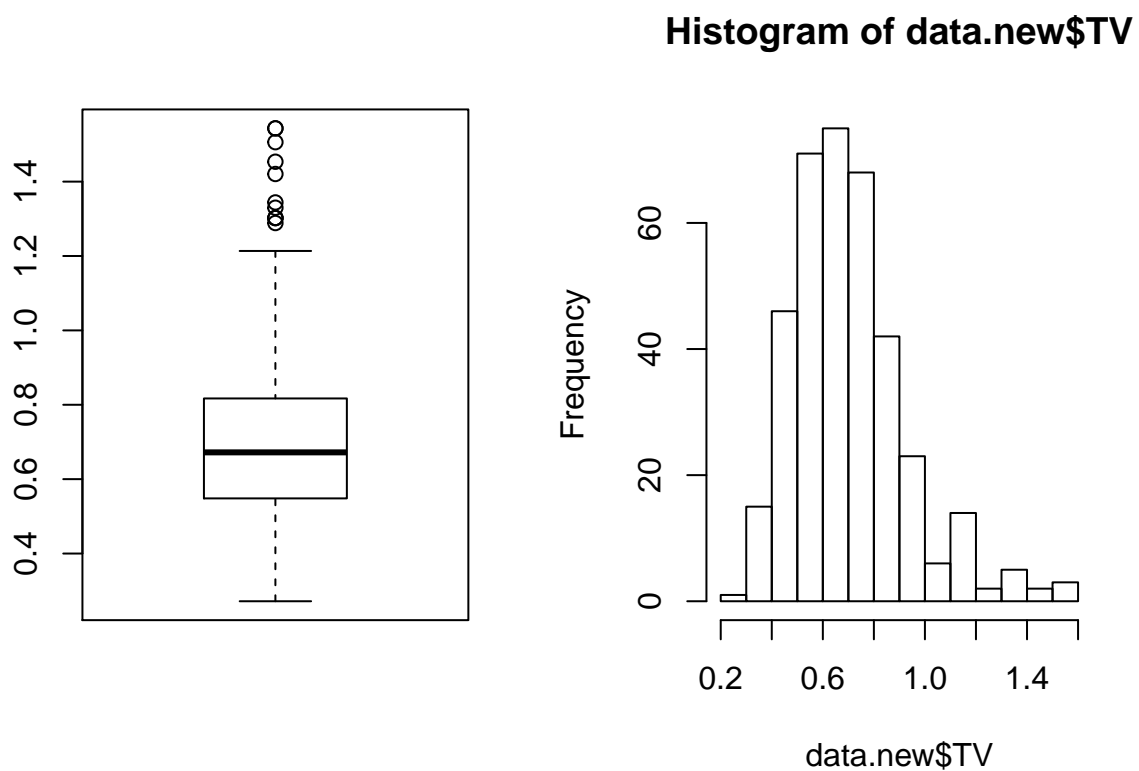
```
# Distribution of average DT  
par(mfrow = c(1,2))  
boxplot(data.new$DT.Avg)  
hist(data.new$DT.Avg)
```



Histogram of data.new\$DT.Avg



```
# Distribution of TV
par(mfrow = c(1,2))
boxplot(data.new$TV)
hist(data.new$DT.Avg)
```

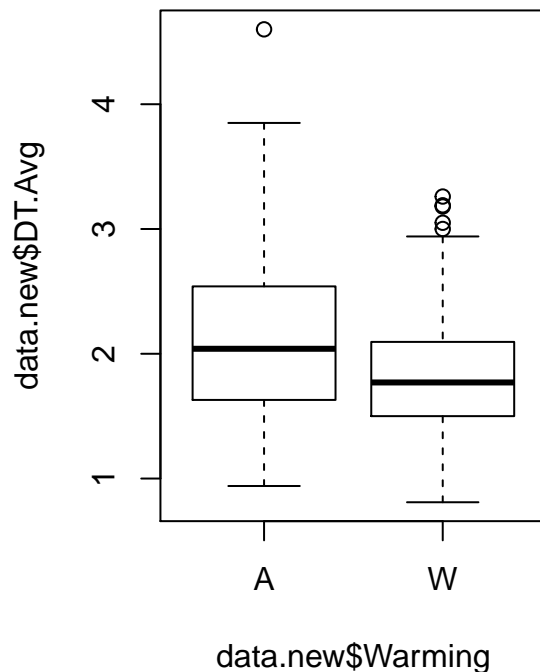
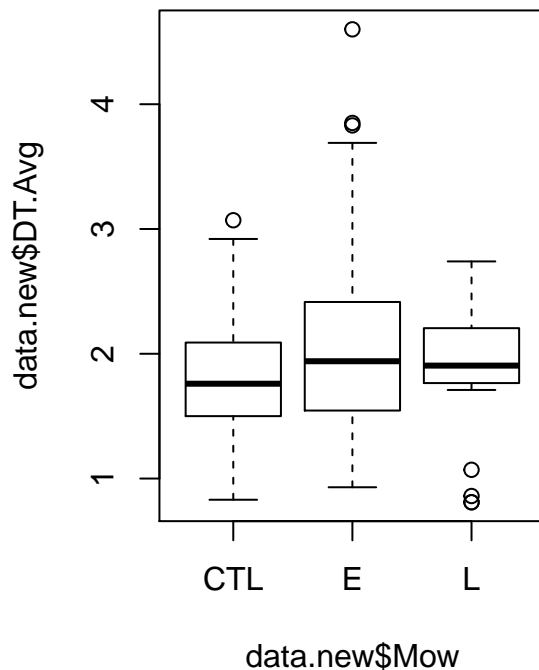


Does drop time/terminal velocity vary by treatment?

Drop Time

Boxplot

```
# Warming and mowing vs. average DT  
par(mfrow = c(1,2))  
boxplot(data.new$DT.Avg ~ data.new$Mow)  
boxplot(data.new$DT.Avg ~ data.new$Warming)
```



ANOVA: Warming and Mowing Alone

```
## ANOVA
# warming
mod.warm = lm(DT.Avg ~ Warming, data= data.new)
summary(mod.warm)

##
## Call:
## lm(formula = DT.Avg ~ Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.17028 -0.38097 -0.05097  0.34903  2.48972
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   2.11028    0.04239   49.78 < 2e-16 ***
## WarmingW      -0.31931    0.05848   -5.46 8.74e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.564 on 371 degrees of freedom
## Multiple R-squared:  0.07438,    Adjusted R-squared:  0.07188
## F-statistic: 29.81 on 1 and 371 DF,  p-value: 8.737e-08
```

```
# mowYN
mod.mowYN = lm(DT.Avg ~ MowYN, data= data.new)
summary(mod.mowYN)

##
## Call:
## lm(formula = DT.Avg ~ MowYN, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.19971 -0.38971 -0.07685  0.33029  2.59029
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.81685     0.05078  35.781 < 2e-16 ***
## MowYN        0.19287     0.06291   3.066  0.00233 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5789 on 371 degrees of freedom
## Multiple R-squared:  0.02471,    Adjusted R-squared:  0.02208
## F-statistic: 9.399 on 1 and 371 DF,  p-value: 0.00233

# early vs. late mowing
mod.mow = lm(DT.Avg ~ Mow, data= data.new)
summary(mod.mow)
```

```
##
## Call:
## lm(formula = DT.Avg ~ Mow, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.0937 -0.3968 -0.0737  0.3363  2.5763
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.81685     0.05076  35.795 < 2e-16 ***
## MowE         0.20685     0.06407   3.228  0.00136 **
## MowL         0.06524     0.12857   0.507  0.61218
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5787 on 370 degrees of freedom
## Multiple R-squared:  0.02811,    Adjusted R-squared:  0.02286
## F-statistic: 5.351 on 2 and 370 DF,  p-value: 0.005119

TukeyHSD(aov(DT.Avg ~ Mow, data= data.new))
```

```
## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = DT.Avg ~ Mow, data = data.new)
##
## $Mow
```

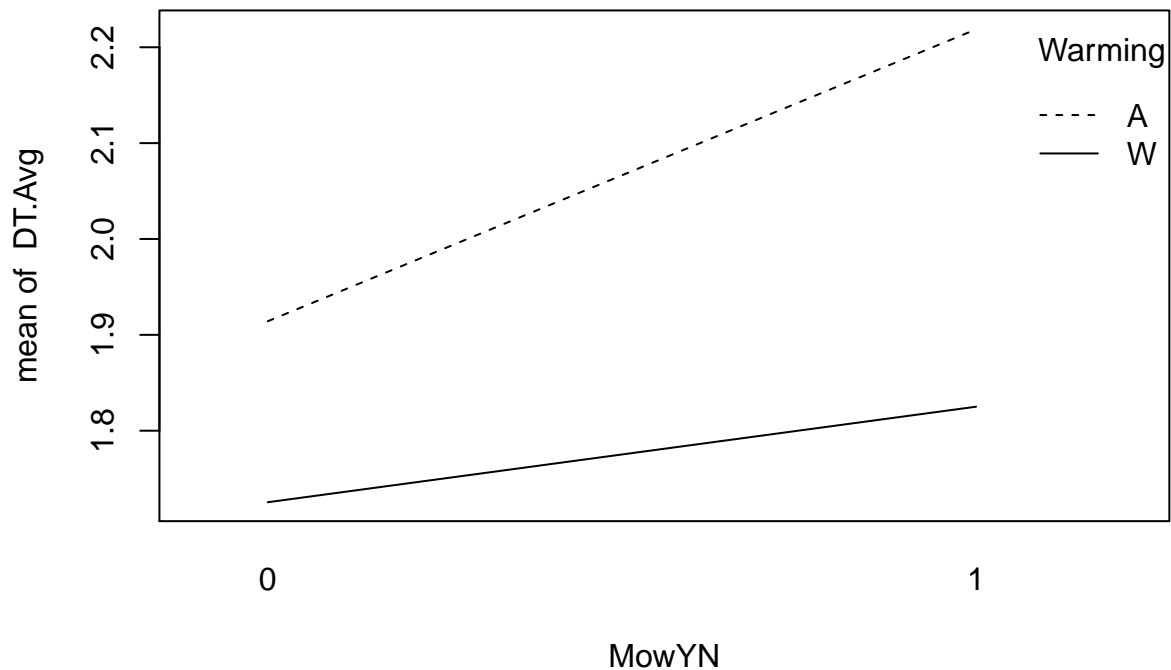
```
##           diff           lwr           upr           p adj
## E-CTL  0.20685248  0.05607353  0.3576314  0.0038699
## L-CTL  0.06523718 -0.23731813  0.3677925  0.8677880
## L-E    -0.14161530 -0.43443289  0.1512023  0.4912560
```

ANOVA: Warming and Mowing Multivariate

```
# interaction
mod.int = lm(DT.Avg ~ MowYN + Warming + MowYN:Warming, data= data.new)
summary(mod.int)

##
## Call:
## lm(formula = DT.Avg ~ MowYN + Warming + MowYN:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.27868 -0.38504 -0.01413  0.33496  2.38132
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1.91413    0.06997   27.356 < 2e-16 ***
## MowYN           0.30456    0.08719    3.493 0.000535 ***
## WarmingW       -0.18875    0.09747   -1.937 0.053557 .
## MowYN:WarmingW -0.20489    0.12082   -1.696 0.090748 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5554 on 369 degrees of freedom
## Multiple R-squared:  0.1073, Adjusted R-squared:  0.1001
## F-statistic: 14.79 on 3 and 369 DF, p-value: 4.107e-09
anova(mod.int)

## Analysis of Variance Table
##
## Response: DT.Avg
##           Df Sum Sq Mean Sq F value    Pr(>F)
## MowYN       1   3.150   3.1503  10.2134  0.001514 **
## Warming     1   9.647   9.6474  31.2775 4.361e-08 ***
## MowYN:Warming 1   0.887   0.8871   2.8761 0.090748 .
## Residuals  369 113.817   0.3084
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
with(data.new, interaction.plot(x.factor = MowYN, Warming, response = DT.Avg))
```



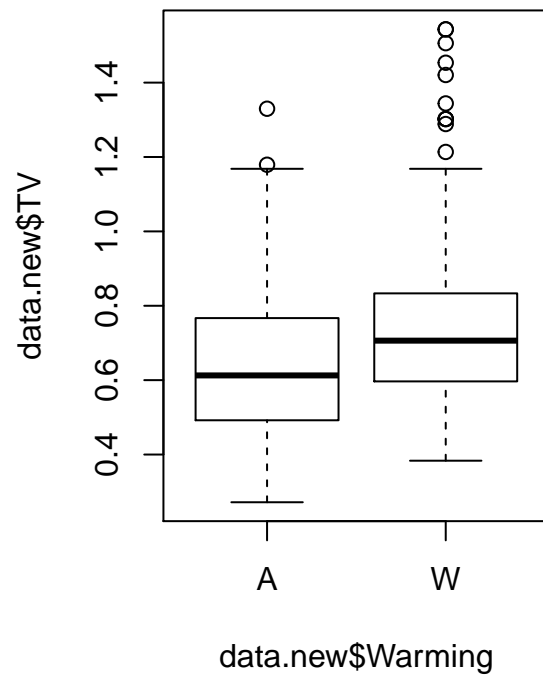
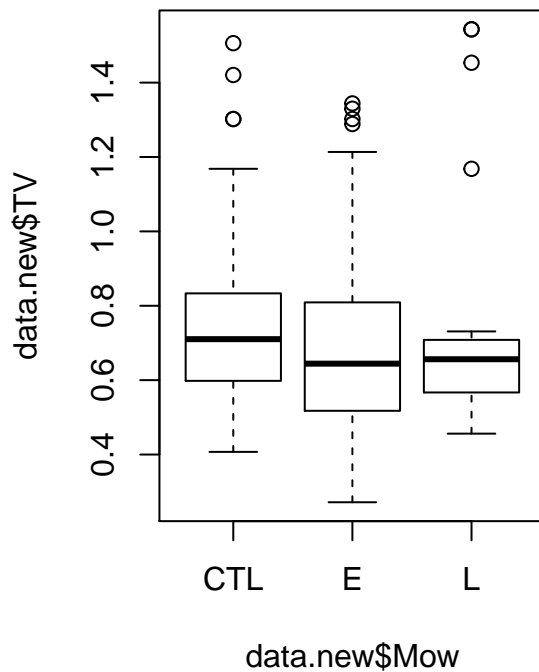
Conclusions:

1. Mowing (regardless of timing) significantly increases drop time. This difference appears to be driven by the early mow treatment, but it's not clear whether late mow shows no effect because there is truly no effect or because there are too few data. **Question: Group all mowing together into mowing Y/N or exclude late mow data points?**
2. Warming significantly decreases drop time. But there does not appear to be a significant interaction between the two parameters.

Terminal Velocity

Boxplot

```
# Warming and mowing vs. TV
par(mfrow = c(1,2))
boxplot(data.new$TV ~ data.new$Mow)
boxplot(data.new$TV ~ data.new$Warming)
```

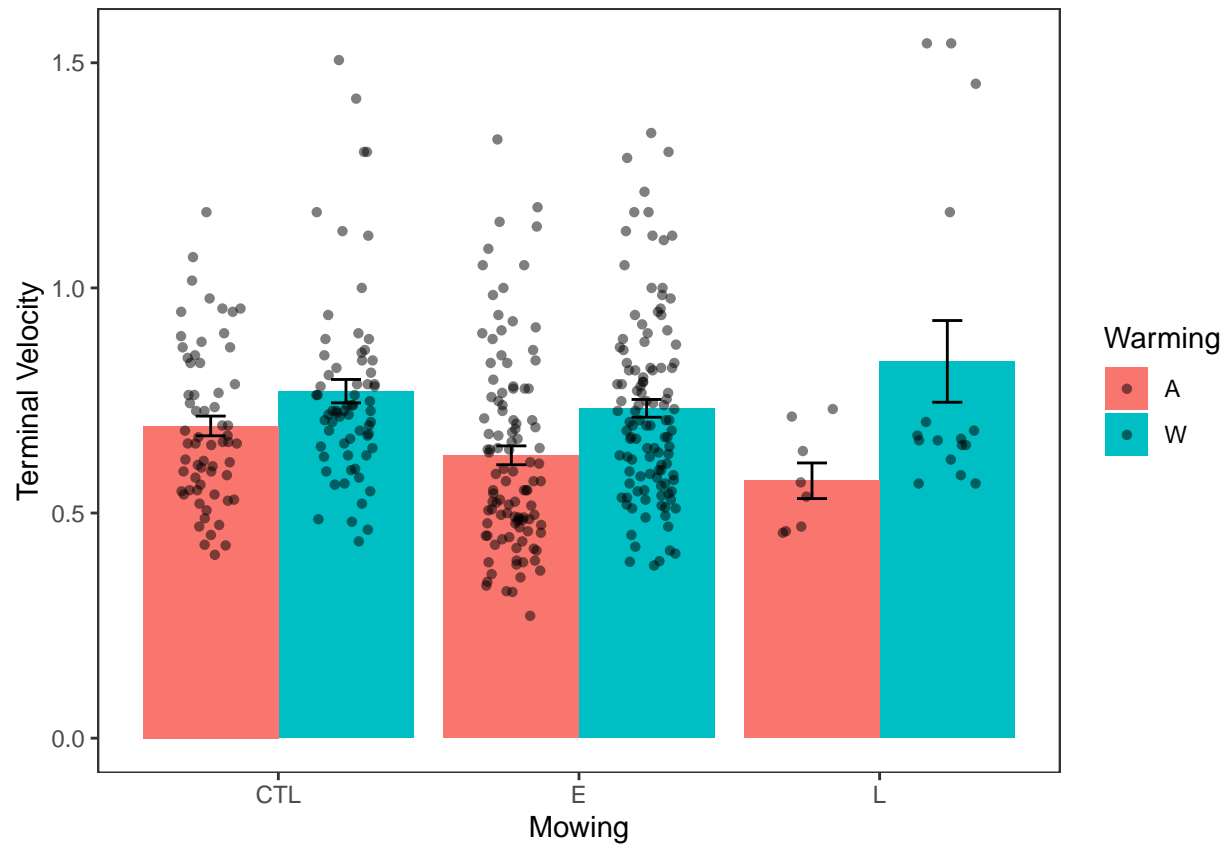


```

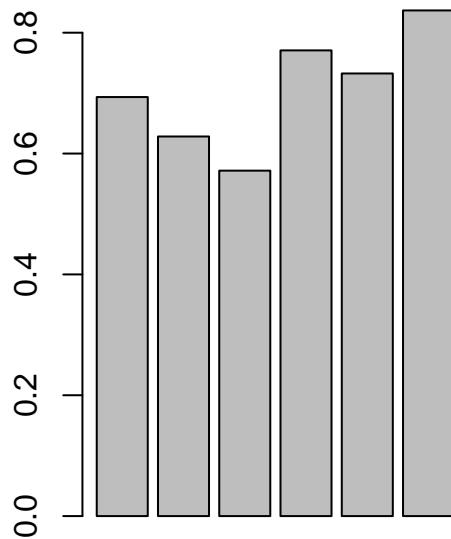
barplot.dat = aggregate(data.new$TV, by = list(Mowing = data.new$Mow, Warming = data.new$Warming), FUN = function(x) {
  barplot.dat = do.call(data.frame, barplot.dat)
  barplot.dat$SE = barplot.dat$x.sd / sqrt(barplot.dat$x.n)
  colnames(barplot.dat) = c("Mowing", "Warming", "Mean", "SD", "n", "SE")

  ggplot(data = barplot.dat, aes(Mowing, Mean, fill = Warming)) +
    geom_bar(stat = "identity", position = position_dodge(0.9)) +
    geom_point(data = data.new, aes(x = Mow, group = Warming, y = TV), position = position_jitterdodge(dodgewidth = 0.9)) +
    geom_errorbar(aes(ymin = Mean - SE, ymax = Mean + SE), width = 0.2, position = position_dodge(0.9)) +
    labs(y = "Terminal Velocity") +
    theme_bw() +
    theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank())
})

```

```
barplot(height = barplot.dat$Mean, )
```



ANOVA: Warming and Mowing Alone

```
## ANOVA
# warming
mod.warm = lm(TV ~ Warming, data= data.new)
summary(mod.warm)

##
## Call:
## lm(formula = TV ~ Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.37715 -0.15676 -0.03913  0.09962  0.78914
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.64889    0.01616  40.153 < 2e-16 ***
## WarmingW     0.10519    0.02229   4.718 3.37e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.215 on 371 degrees of freedom
## Multiple R-squared:  0.05661,    Adjusted R-squared:  0.05407
## F-statistic: 22.26 on 1 and 371 DF,  p-value: 3.372e-06
```

```

# mowYN
mod.mowYN = lm(TV ~ MowYN, data= data.new)
summary(mod.mowYN)

##
## Call:
## lm(formula = TV ~ MowYN, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.41685 -0.15440 -0.03102  0.10255  0.85462
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.73327    0.01932  37.947  <2e-16 ***
## MowYN        -0.04468    0.02394  -1.866   0.0628 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2203 on 371 degrees of freedom
## Multiple R-squared:  0.009301,    Adjusted R-squared:  0.006631
## F-statistic: 3.483 on 1 and 371 DF,  p-value: 0.06279

# early vs. late mowing
mod.mow = lm(TV ~ Mow, data= data.new)
summary(mod.mow)

```

```

##
## Call:
## lm(formula = TV ~ Mow, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.4103 -0.1546 -0.0377  0.1057  0.7948
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.73327    0.01930  37.996  <2e-16 ***
## MowE         -0.05124    0.02436  -2.103   0.0361 *
## MowL          0.01518    0.04889   0.311   0.7563
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.22 on 370 degrees of freedom
## Multiple R-squared:  0.01455,    Adjusted R-squared:  0.009224
## F-statistic: 2.732 on 2 and 370 DF,  p-value: 0.06643

```

```

TukeyHSD(aov(TV ~ Mow, data= data.new))

```

```

##      Tukey multiple comparisons of means
##      95% family-wise confidence level
##
## Fit: aov(formula = TV ~ Mow, data = data.new)
##
## $Mow

```

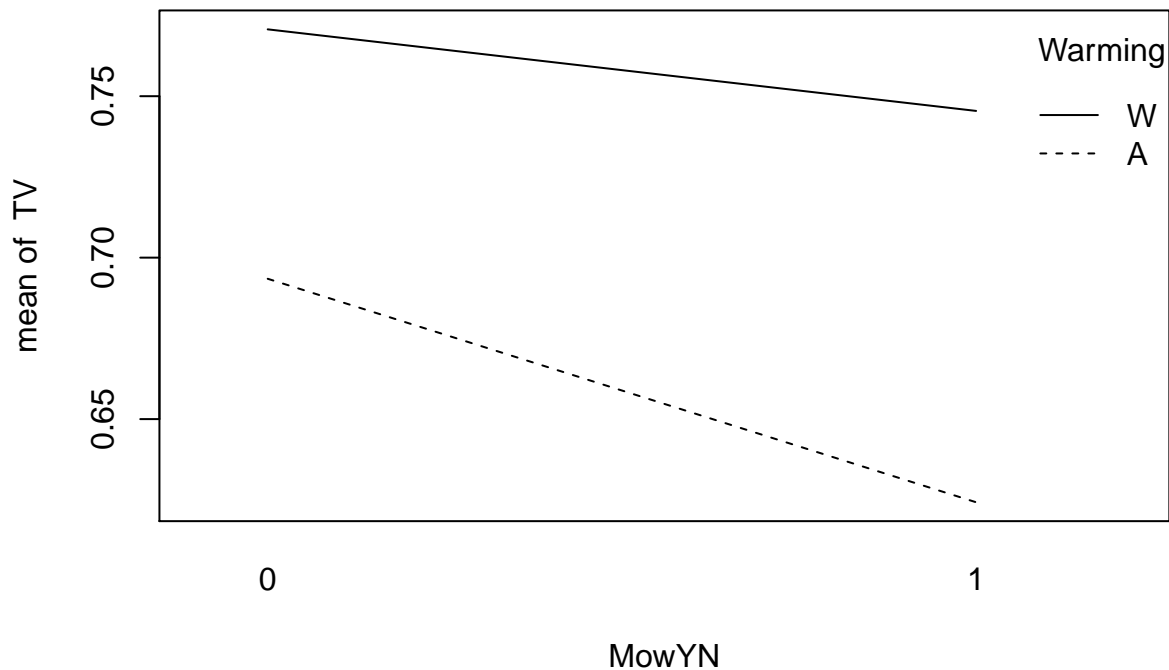
```
##           diff           lwr           upr           p adj
## E-CTL -0.05124079 -0.10856889 0.00608732 0.0905348
## L-CTL 0.01518016 -0.09985528 0.13021561 0.9482427
## L-E    0.06642095 -0.04491209 0.17775400 0.3399106
```

ANOVA: Warming and Mowing Multivariate

```
# interaction (mow YN)
mod.intYN = lm(TV ~ MowYN + Warming + MowYN:Warming, data= data.new)
summary(mod.intYN)

##
## Call:
## lm(formula = TV ~ MowYN + Warming + MowYN:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.36201 -0.14715 -0.04395  0.09003  0.79777
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.69346    0.02698   25.699  <2e-16 ***
## MowYN          -0.06921    0.03362   -2.058   0.0403 *
## WarmingW        0.07724    0.03759    2.055   0.0406 *
## MowYN:WarmingW  0.04395    0.04659    0.943   0.3461
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2142 on 369 degrees of freedom
## Multiple R-squared:  0.06885,    Adjusted R-squared:  0.06128
## F-statistic: 9.095 on 3 and 369 DF,  p-value: 8.023e-06
anova(mod.intYN)

## Analysis of Variance Table
##
## Response: TV
##           Df Sum Sq Mean Sq F value    Pr(>F)
## MowYN       1  0.1691  0.16908   3.6858  0.05565 .
## Warming     1  1.0417  1.04171  22.7092 2.715e-06 ***
## MowYN:Warming 1  0.0408  0.04082   0.8899  0.34612
## Residuals  369 16.9267  0.04587
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
with(data.new, interaction.plot(x.factor = MowYN,Warming,response = TV))
```



```
anova(mod.warm, lm(TV~MowYN + Warming, data = data.new), mod.intYN)
```

```
## Analysis of Variance Table
##
## Model 1: TV ~ Warming
## Model 2: TV ~ MowYN + Warming
## Model 3: TV ~ MowYN + Warming + MowYN:Warming
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1      371 17.149
## 2      370 16.968   1  0.181663 3.9602 0.04732 *
## 3      369 16.927   1  0.040821 0.8899 0.34612
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# no interaction (E/L mow)
mod.mowWarm = lm(TV ~ Mow + Warming, data = data.new)
summary(mod.mowWarm)
```

```
##
## Call:
## lm(formula = TV ~ Mow + Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.35659 -0.14554 -0.04405  0.08997  0.76007
##
## Coefficients:
```

```
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.6796344  0.0220039  30.887 < 2e-16 ***
## MowE         -0.0513029  0.0237031  -2.164  0.0311 *
## MowL         -0.0005629  0.0476820  -0.012  0.9906
## WarmingW      0.1040641  0.0222599   4.675 4.13e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2141 on 369 degrees of freedom
## Multiple R-squared:  0.06965, Adjusted R-squared:  0.06209
## F-statistic: 9.209 on 3 and 369 DF, p-value: 6.881e-06

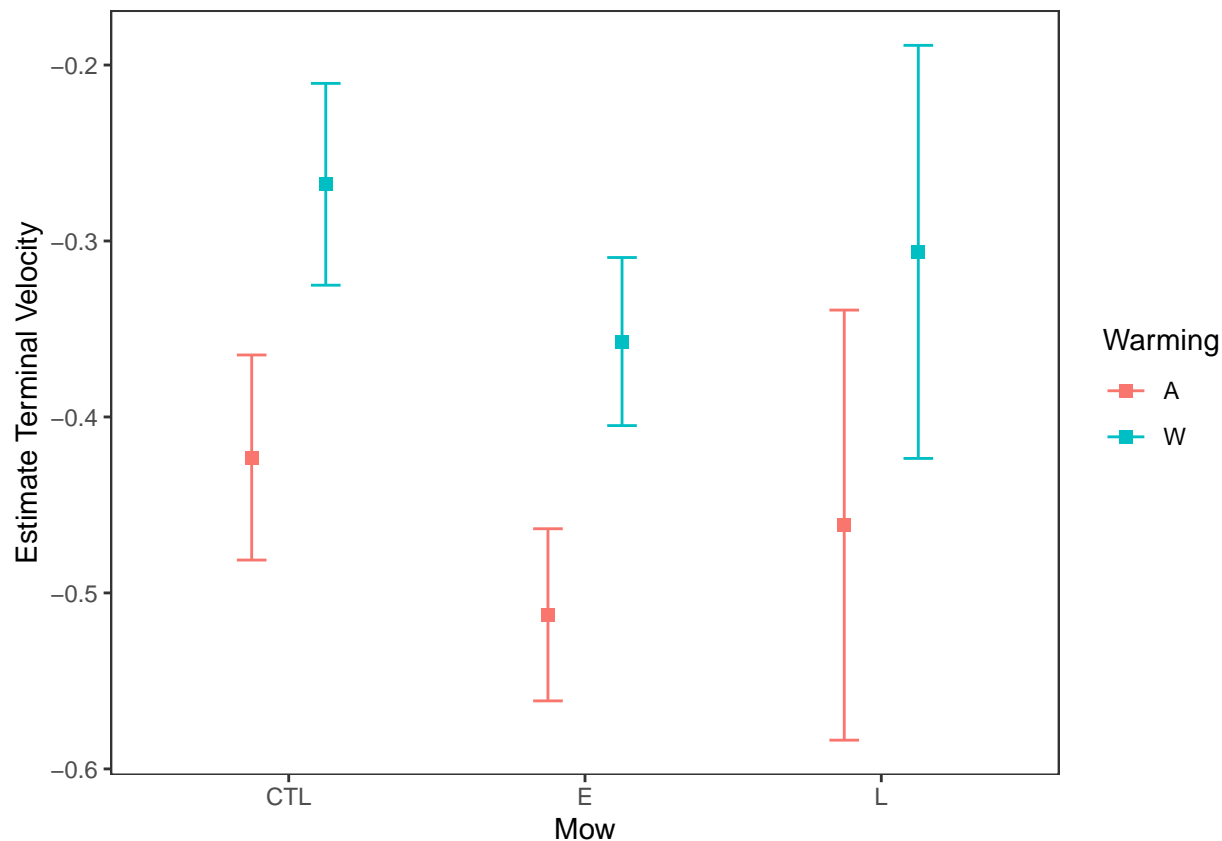
mowWarm.dat = expand.grid(Mow = c("CTL", "E", "L"), Warming = c("A", "W"))
mowWarm.dat = cbind(mowWarm.dat, predict(mod.mowWarm, newdata = mowWarm.dat, interval = "confidence"))
mowWarm.dat = do.call(data.frame, mowWarm.dat)

mod.mowWarm.log = lm(log(TV) ~ Mow + Warming, data = data.new)
summary(mod.mowWarm.log)

##
## Call:
## lm(formula = log(TV) ~ Mow + Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.79049 -0.19722 -0.03381  0.16161  0.79745
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.42305    0.02963 -14.278 < 2e-16 ***
## MowE         -0.08938    0.03192  -2.800  0.00538 **
## MowL         -0.03841    0.06421  -0.598  0.55002
## WarmingW      0.15528    0.02997   5.180 3.65e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2883 on 369 degrees of freedom
## Multiple R-squared:  0.0869, Adjusted R-squared:  0.07947
## F-statistic: 11.71 on 3 and 369 DF, p-value: 2.418e-07

mowWarm.dat = expand.grid(Mow = c("CTL", "E", "L"), Warming = c("A", "W"))
mowWarm.dat = cbind(mowWarm.dat, predict(mod.mowWarm.log, newdata = mowWarm.dat, interval = "confidence"))
mowWarm.dat = do.call(data.frame, mowWarm.dat)

ggplot(data = mowWarm.dat, aes(x = Mow, color = Warming))+
  geom_point(aes(y = fit), position = position_dodge(0.5), size = 2, shape = 15)+
  geom_errorbar(aes(ymin = lwr, ymax = upr), width = 0.2, position = position_dodge(0.5))+
  labs(y = "Estimate Terminal Velocity")+
  theme_bw()+
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank())
```



```
# interaction (including E/L mow differentiation)
mod.int = lm(TV ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)

##
## Call:
## lm(formula = TV ~ Mow + Warming + Mow:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.35648 -0.15111 -0.03901  0.09852  0.73533
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.69346    0.02692  25.764  <2e-16 ***
## MowE          -0.06524    0.03399  -1.920   0.0557 .
## MowL          -0.12179    0.08018  -1.519   0.1297
## WarmingW       0.07724    0.03749   2.060   0.0401 *
## MowE:WarmingW  0.02704    0.04733   0.571   0.5681
## MowL:WarmingW  0.18792    0.09982   1.883   0.0605 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2136 on 367 degrees of freedom
## Multiple R-squared:  0.07855,    Adjusted R-squared:  0.066
## F-statistic: 6.257 on 5 and 367 DF,  p-value: 1.38e-05
```

```
anova(mod.int)
```

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

```
##
```

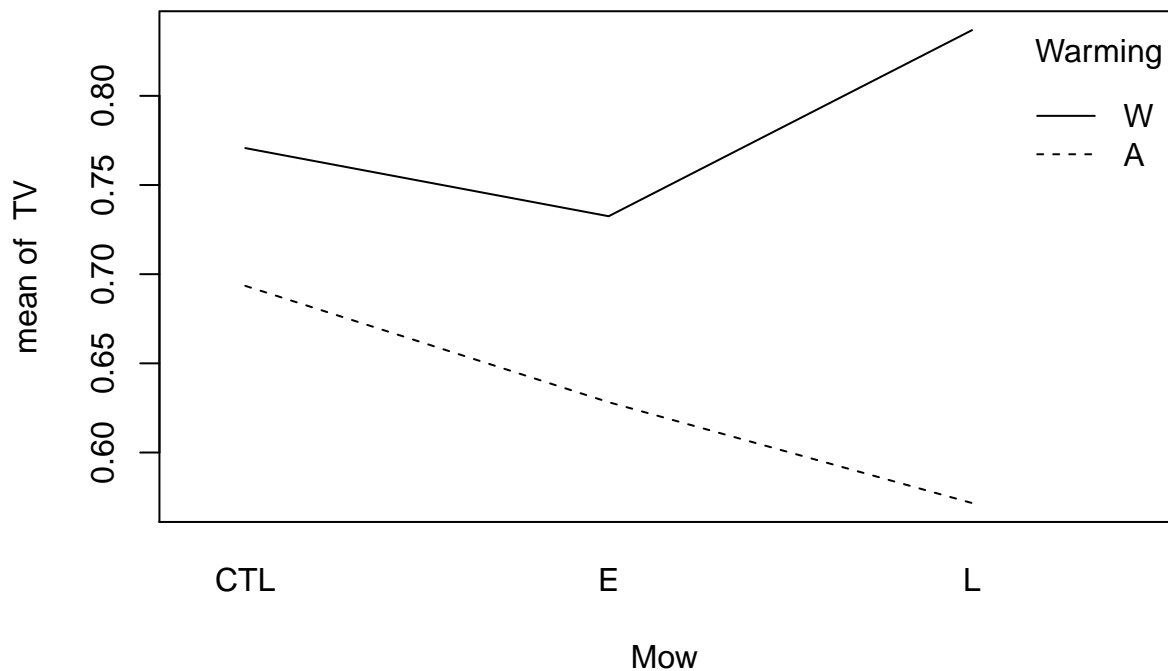
```
## Response: TV
```

```
##           Df Sum Sq Mean Sq F value    Pr(>F)
## Mow         2  0.2645  0.13225   2.8976  0.05642 .
## Warming     1  1.0017  1.00168  21.9468 3.955e-06 ***
## Mow:Warming  2  0.1618  0.08089   1.7723  0.17139
## Residuals  367 16.7503  0.04564
```

```
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
with(data.new, interaction.plot(x.factor = Mow,Warming,response = TV))
```



```
# partial F test: compare full model to warming only model
```

```
anova(mod.warm, mod.mowWarm, mod.int)
```

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

```
##
```

```
## Model 1: TV ~ Warming
```

```
## Model 2: TV ~ Mow + Warming
```

```
## Model 3: TV ~ Mow + Warming + Mow:Warming
```

```
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1     371 17.149
## 2     369 16.912  2   0.23705 2.5969 0.07587 .
## 3     367 16.750  2   0.16178 1.7723 0.17139
```



```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conclusions:

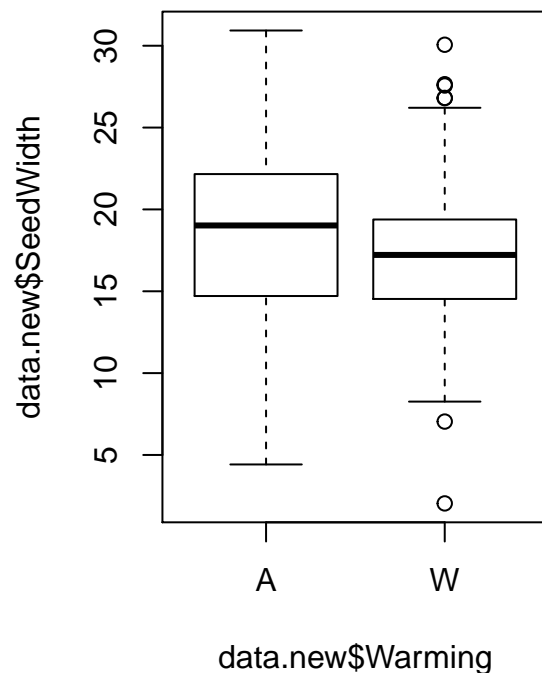
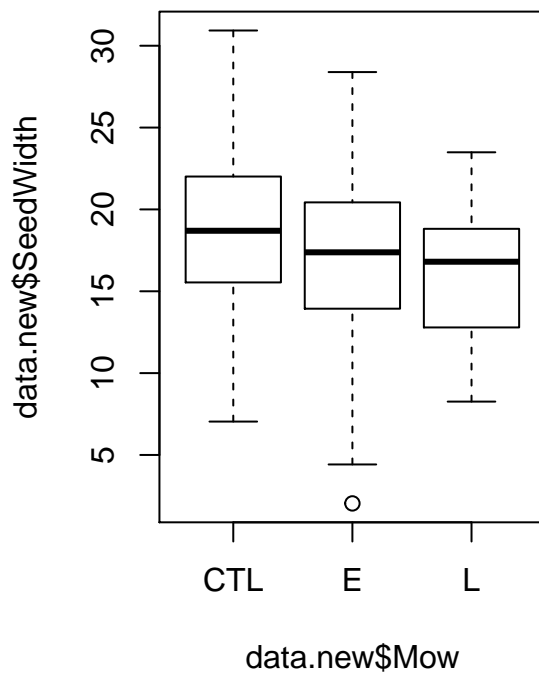
1. Mowing has weak or no effect on terminal velocity.
2. Warming significantly increases terminal velocity. There may be a weak interaction between late mowing and warmed plants which further increases terminal velocity, though partial F-test does not suggest these terms add more information.

Do seed shape parameters change by treatment?

Seed Width

Boxplot

```
# Warming and mowing vs. seedwidth
par(mfrow = c(1,2))
boxplot(data.new$SeedWidth ~ data.new$Mow)
boxplot(data.new$SeedWidth ~ data.new$Warming)
```



ANOVA: Warming and Mowing Alone

```
## ANOVA
# warming
```

```

mod.warm = lm(SeedWidth ~ Warming, data= data.new)
summary(mod.warm)

##
## Call:
## lm(formula = SeedWidth ~ Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -15.1141  -3.2341   0.3355   3.0659  12.9059
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  18.3345     0.3502  52.350  <2e-16 ***
## WarmingW      -1.1804     0.4831  -2.443   0.015 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.659 on 371 degrees of freedom
## Multiple R-squared:  0.01584,    Adjusted R-squared:  0.01318
## F-statistic: 5.969 on 1 and 371 DF,  p-value: 0.01502

```

mowYN

```

mod.mowYN = lm(SeedWidth ~ MowYN, data= data.new)
summary(mod.mowYN)

##
## Call:
## lm(formula = SeedWidth ~ MowYN, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -15.0588  -3.2388  -0.0288   3.2312  12.0655
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  18.8645     0.4052  46.552  < 2e-16 ***
## MowYN        -1.7657     0.5021  -3.517 0.000491 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.62 on 371 degrees of freedom
## Multiple R-squared:  0.03226,    Adjusted R-squared:  0.02965
## F-statistic: 12.37 on 1 and 371 DF,  p-value: 0.0004909

```

early vs. late mowing

```

mod.mow = lm(SeedWidth ~ Mow, data= data.new)
summary(mod.mow)

##
## Call:
## lm(formula = SeedWidth ~ Mow, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max

```

```
## -15.1627 -3.2827 0.0055 3.1455 12.0655
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) 18.8645 0.4052 46.559 < 2e-16 ***
## MowE -1.6618 0.5115 -3.249 0.00126 **
## MowL -2.7133 1.0264 -2.644 0.00855 **
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.62 on 370 degrees of freedom
## Multiple R-squared: 0.03518, Adjusted R-squared: 0.02997
## F-statistic: 6.746 on 2 and 370 DF, p-value: 0.001325
```

```
TukeyHSD(aov(SeedWidth ~ Mow, data= data.new))
```

```
## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = SeedWidth ~ Mow, data = data.new)
##
## $Mow
## diff lwr upr p adj
## E-CTL -1.661844 -2.865461 -0.4582281 0.0036103
## L-CTL -2.713288 -5.128483 -0.2980938 0.0232028
## L-E -1.051444 -3.388906 1.2860178 0.5404945
```

ANOVA: Warming and Mowing Multivariate

```
# interaction (including E/L mow differentiation)
mod.int = lm(SeedWidth ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)
```

```
##
## Call:
## lm(formula = SeedWidth ~ Mow + Warming + Mow:Warming, data = data.new)
##
## Residuals:
## Min 1Q Median 3Q Max
## -14.3077 -3.0324 0.1123 3.0638 12.0376
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) 18.89238 0.57782 32.696 <2e-16 ***
## MowE -0.77823 0.72960 -1.067 0.2868
## MowL -2.03113 1.72138 -1.180 0.2388
## WarmingW -0.05402 0.80487 -0.067 0.9465
## MowE:WarmingW -1.71243 1.01607 -1.685 0.0928 .
## MowL:WarmingW -1.01098 2.14284 -0.472 0.6374
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.586 on 367 degrees of freedom
## Multiple R-squared: 0.05679, Adjusted R-squared: 0.04394
## F-statistic: 4.419 on 5 and 367 DF, p-value: 0.0006394
```

```
anova(mod.int)
```

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

```
##
```

```
## Response: SeedWidth
```

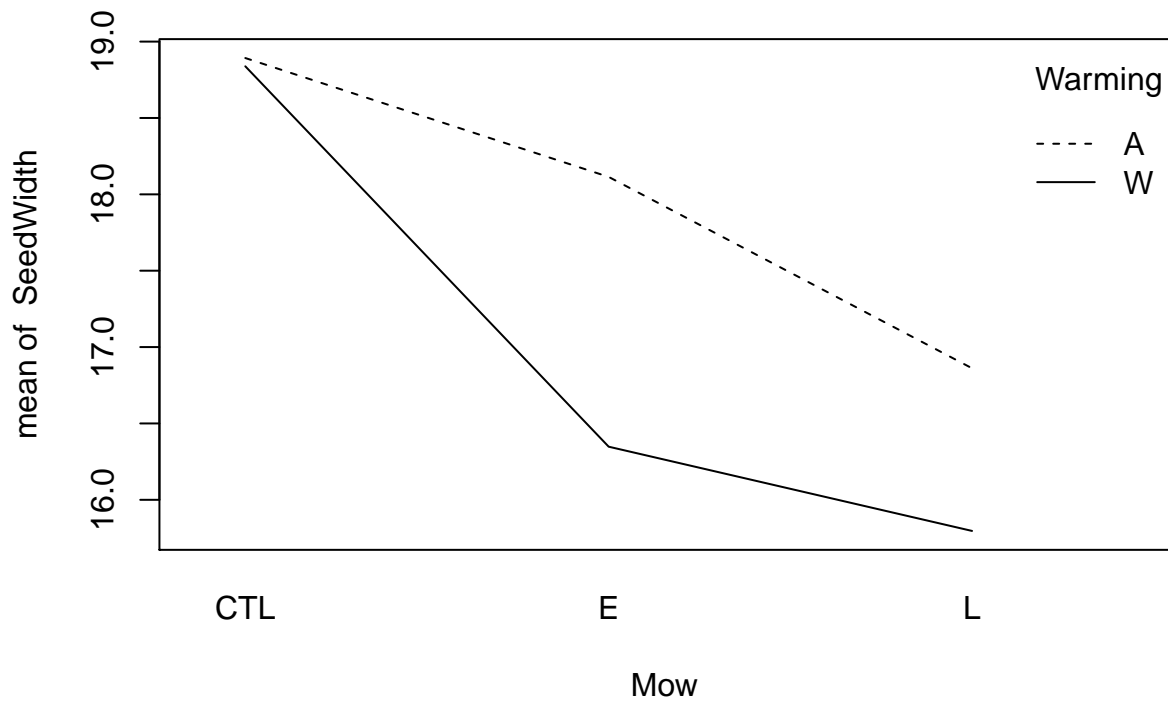
```
##           Df Sum Sq Mean Sq F value    Pr(>F)
## Mow         2   288.0   143.976    6.8448 0.001206 **
## Warming      1   117.0    117.043    5.5644 0.018853 *
## Mow:Warming  2    59.8    29.883    1.4207 0.242877
## Residuals  367  7719.6    21.034
```

```
## ---
```

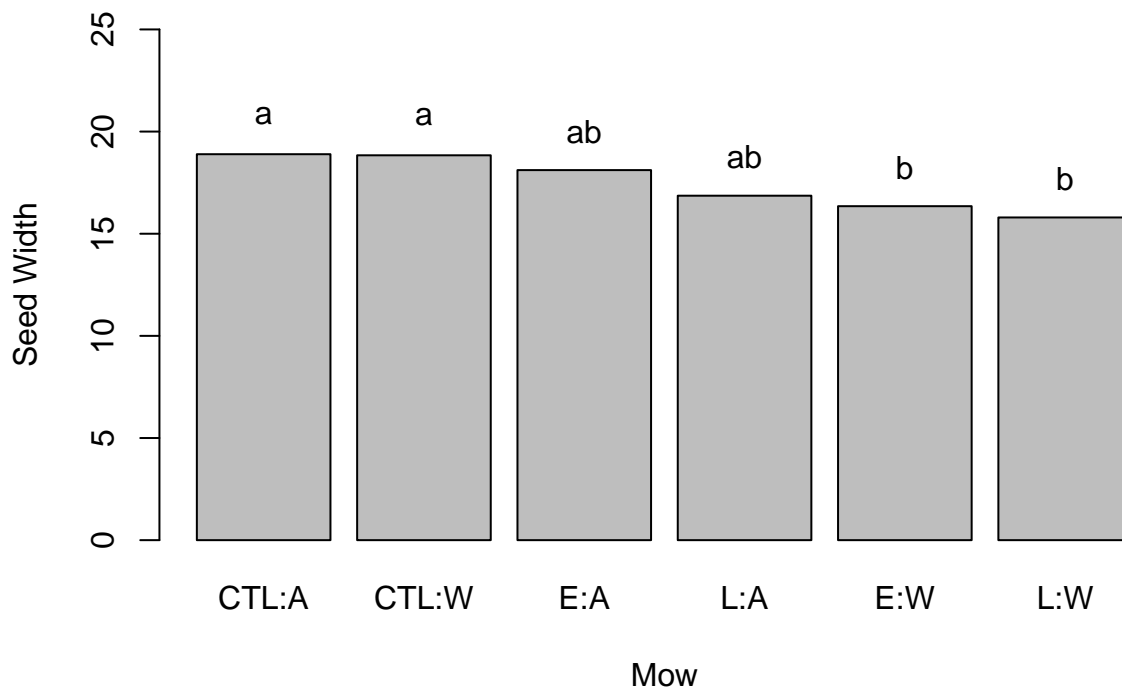
```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
par(mfrow = c(1,1))
```

```
with(data.new, interaction.plot(x.factor = Mow,Warming,response = SeedWidth))
```



```
out = HSD.test(aov(SeedWidth ~ Mow + Warming + Mow:Warming, data= data.new), c("Mow","Warming"))
bar.group(out$groups, ylim = c(0,25), xlab = "Mow", ylab = "Seed Width")
```



```
# partial F test: compare full model to warming only model
anova(mod.mow, lm(SeedWidth~Mow + Warming, data = data.new), mod.int)
```

```
## Analysis of Variance Table
##
## Model 1: SeedWidth ~ Mow
## Model 2: SeedWidth ~ Mow + Warming
## Model 3: SeedWidth ~ Mow + Warming + Mow:Warming
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1      370 7896.4
## 2      369 7779.3  1   117.043 5.5644 0.01885 *
## 3      367 7719.6  2    59.766 1.4207 0.24288
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction (excluding E/L mow differentiation)
mod.intYN = lm(SeedWidth ~ MowYN + Warming + MowYN:Warming, data= data.new)
summary(mod.intYN)
```

```
##
## Call:
## lm(formula = SeedWidth ~ MowYN + Warming + MowYN:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -14.2393  -3.0324   0.1276   3.0638  12.0376
##
```

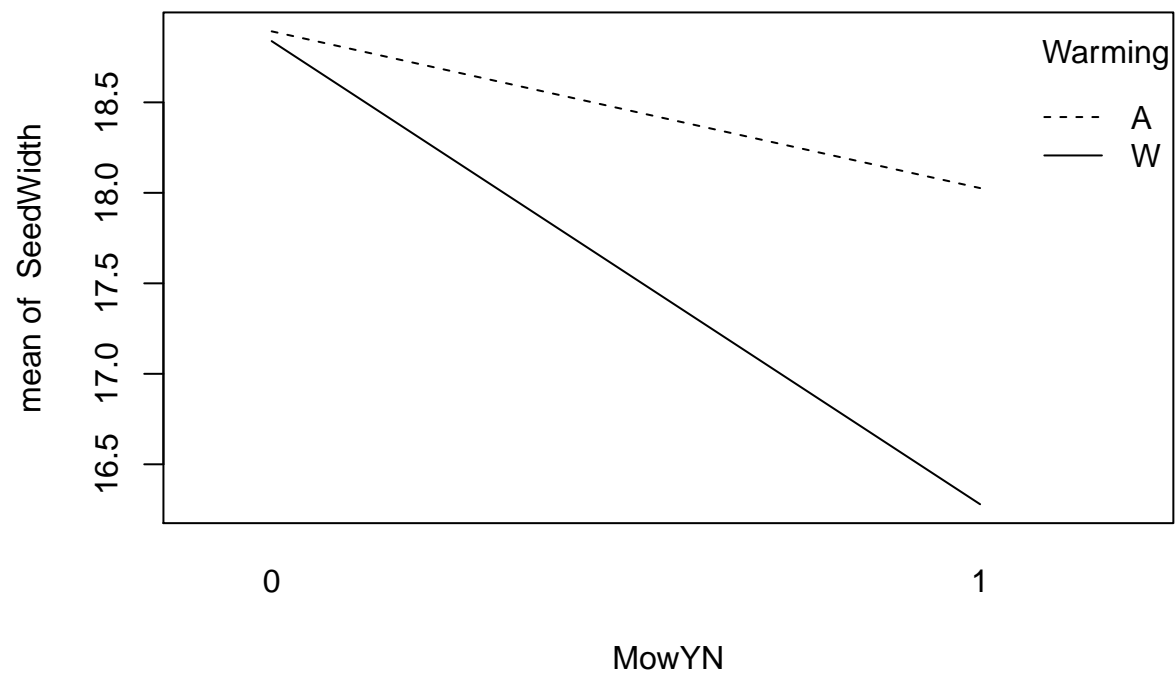
```
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  18.89238    0.57685   32.751  <2e-16 ***
## MowYN        -0.86615    0.71878   -1.205    0.229
## WarmingW     -0.05402    0.80352   -0.067    0.946
## MowYN:WarmingW -1.69290    0.99601   -1.700    0.090 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.579 on 369 degrees of freedom
## Multiple R-squared:  0.05484,    Adjusted R-squared:  0.04715
## F-statistic: 7.137 on 3 and 369 DF,  p-value: 0.0001137
```

```
anova(mod.intYN)
```

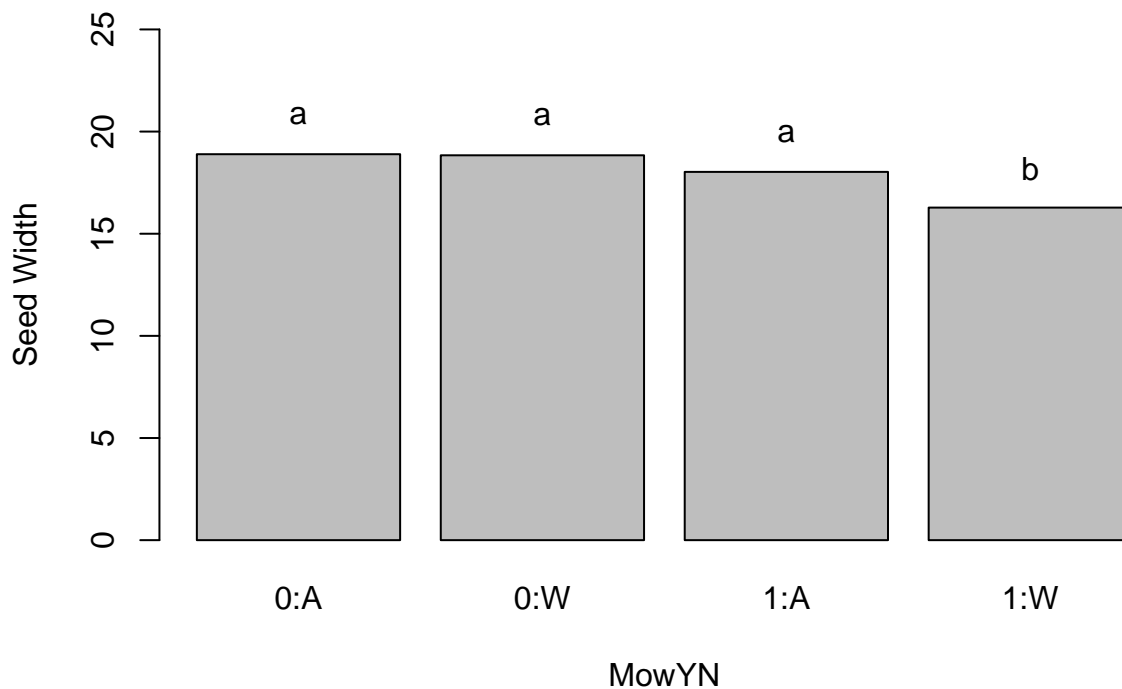
```
## Analysis of Variance Table
##
## Response: SeedWidth
##           Df Sum Sq Mean Sq F value    Pr(>F)
## MowYN       1  264.0  264.040  12.5953 0.0004367 ***
## Warming      1  124.2  124.220   5.9256 0.0153963 *
## MowYN:Warming 1   60.6   60.562   2.8889 0.0900332 .
## Residuals   369 7735.5  20.963
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
par(mfrow = c(1,1))
```

```
with(data.new, interaction.plot(x.factor = MowYN,Warming,response = SeedWidth))
```



```
out = HSD.test(aov(SeedWidth ~ MowYN + Warming + MowYN:Warming, data= data.new), c("MowYN", "Warming"))
bar.group(out$groups, ylim = c(0,25), xlab = "MowYN", ylab = "Seed Width")
```



```
# partial F test: compare full model to warming only model
anova(mod.mow, lm(SeedWidth~MowYN + Warming, data = data.new), mod.intYN)
```

```
## Analysis of Variance Table
##
## Model 1: SeedWidth ~ Mow
## Model 2: SeedWidth ~ MowYN + Warming
## Model 3: SeedWidth ~ MowYN + Warming + MowYN:Warming
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1     370 7896.4
## 2     370 7796.1  0    100.308
## 3     369 7735.5  1     60.562 2.8889 0.09003 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

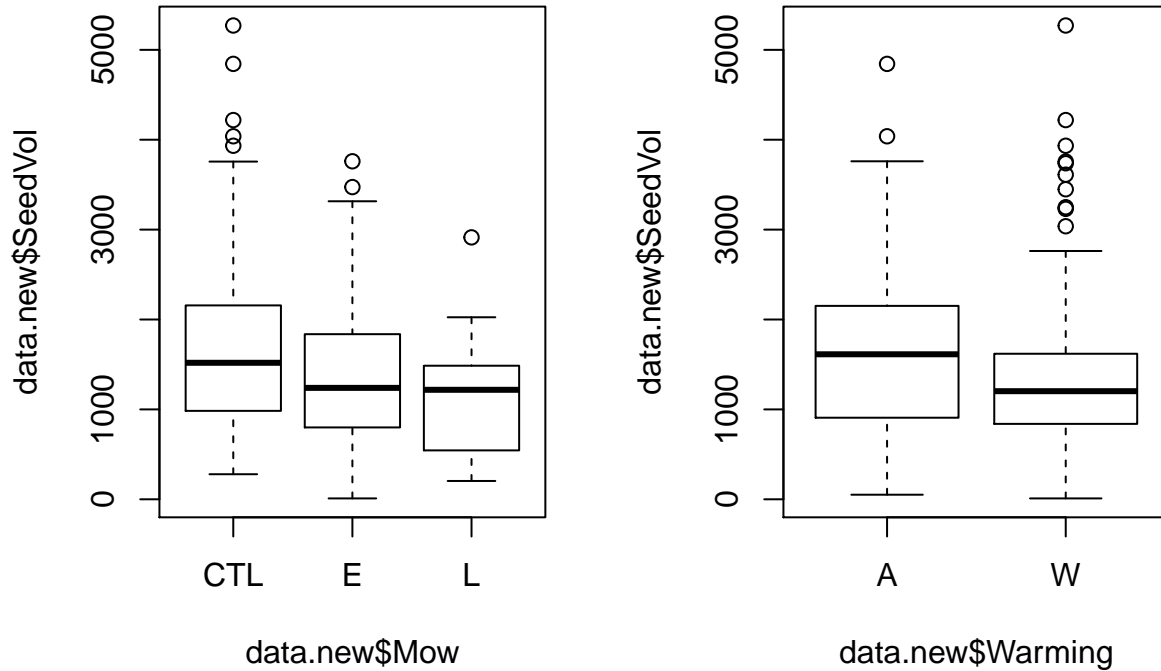
Conclusions:

1. Seed width is significantly reduced by mowing and warming, though there appears to be an interaction. We see a significant decrease in seed width for plants which are mowed and warmed.

Seed Volume

Boxplot

```
# Warming and mowing vs. average DT
par(mfrow = c(1,2))
boxplot(data.new$SeedVol ~ data.new$Mow)
boxplot(data.new$SeedVol ~ data.new$Warming)
```

ANOVA: Warming and Mowing Alone

```
## ANOVA
## warming
mod.warm = lm(SeedVol ~ Warming, data= data.new)
summary(mod.warm)

##
## Call:
## lm(formula = SeedVol ~ Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1568.2  -606.9  -129.8   421.6  3916.5
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1619.31     63.42   25.533  <2e-16 ***
## WarmingW     -265.24     87.49   -3.032   0.0026 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 843.8 on 371 degrees of freedom
## Multiple R-squared:  0.02417,    Adjusted R-squared:  0.02154
```

```
## F-statistic: 9.191 on 1 and 371 DF, p-value: 0.002603
# mowYN
mod.mowYN = lm(SeedVol ~ MowYN, data= data.new)
summary(mod.mowYN)

##
## Call:
## lm(formula = SeedVol ~ MowYN, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1447.5  -640.2  -123.8   462.9  3544.2
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1726.45      73.22  23.580 < 2e-16 ***
## MowYN        -378.39      90.71  -4.171 3.77e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 834.8 on 371 degrees of freedom
## Multiple R-squared:  0.0448, Adjusted R-squared:  0.04223
## F-statistic: 17.4 on 1 and 371 DF, p-value: 3.774e-05
# early vs. late mowing
mod.mow = lm(SeedVol ~ Mow, data= data.new)
summary(mod.mow)

##
## Call:
## lm(formula = SeedVol ~ Mow, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1447.5  -640.2  -134.4   449.6  3544.2
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1726.45      73.18  23.590 < 2e-16 ***
## MowE         -357.99      92.39  -3.875 0.000126 ***
## MowL         -564.52     185.38  -3.045 0.002493 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 834.4 on 370 degrees of freedom
## Multiple R-squared:  0.04821, Adjusted R-squared:  0.04306
## F-statistic: 9.37 on 2 and 370 DF, p-value: 0.0001072
TukeyHSD(aov(SeedVol ~ Mow, data= data.new))

## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = SeedVol ~ Mow, data = data.new)
##
```

```
## $Mow
##          diff          lwr          upr          p adj
## E-CTL -357.9921 -575.3952 -140.5891 0.0003703
## L-CTL -564.5166 -1000.7609 -128.2724 0.0070219
## L-E   -206.5245 -628.7283  215.6793 0.4833293
```

ANOVA: Warming and Mowing Multivariate

```
# interaction (including E/L mow differentiation)
```

```
mod.int = lm(SeedVol ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)
```

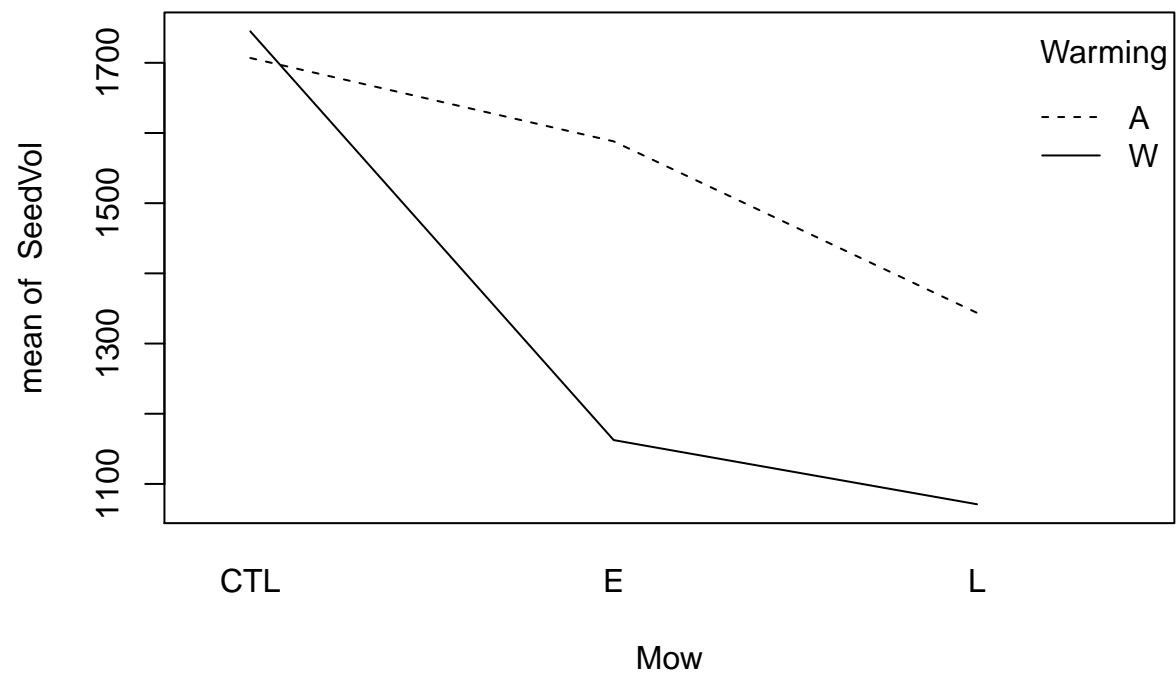
```
##
## Call:
## lm(formula = SeedVol ~ Mow + Warming + Mow:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1537.0  -563.4   -82.3   408.3  3525.8
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    1706.90     103.42  16.505  <2e-16 ***
## MowE           -118.85     130.58   -0.910   0.3633
## MowL           -363.21     308.08   -1.179   0.2392
## WarmingW         37.93     144.05    0.263   0.7925
## MowE:WarmingW  -463.52     181.85   -2.549   0.0112 *
## MowL:WarmingW  -310.57     383.51   -0.810   0.4186
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 820.8 on 367 degrees of freedom
## Multiple R-squared:  0.08645,    Adjusted R-squared:  0.074
## F-statistic: 6.946 on 5 and 367 DF,  p-value: 3.257e-06
```

```
anova(mod.int)
```

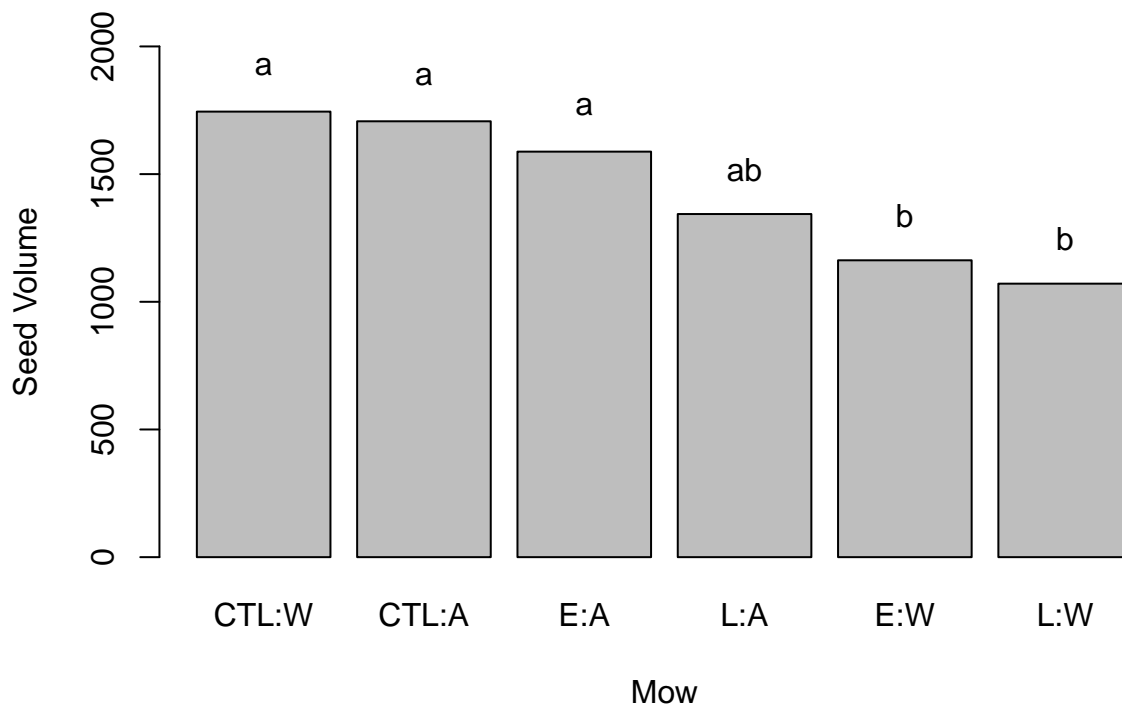
```
## Analysis of Variance Table
##
## Response: SeedVol
##           Df    Sum Sq Mean Sq F value    Pr(>F)
## Mow         2  13048600 6524300   9.6833 7.976e-05 ***
## Warming      1   5970599 5970599   8.8615 0.003106 **
## Mow:Warming  2   4379380 2189690   3.2499 0.039896 *
## Residuals  367 247272208  673766
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
par(mfrow = c(1,1))
```

```
with(data.new, interaction.plot(x.factor = Mow,Warming,response = SeedVol))
```



```
out = HSD.test(aov(SeedVol ~ Mow + Warming + Mow:Warming, data= data.new), c("Mow", "Warming"))
bar.group(out$groups, ylim = c(0,2000), xlab = "Mow", ylab = "Seed Volume")
```



```
# partial F test: compare full model to warming only model
anova(mod.mow, lm(SeedVol~Mow + Warming, data = data.new), mod.int)
```

```
## Analysis of Variance Table
##
## Model 1: SeedVol ~ Mow
## Model 2: SeedVol ~ Mow + Warming
## Model 3: SeedVol ~ Mow + Warming + Mow:Warming
##   Res.Df      RSS Df Sum of Sq    F    Pr(>F)
## 1      370 257622187
## 2      369 251651588   1   5970599 8.8615 0.003106 **
## 3      367 247272208   2   4379380 3.2499 0.039896 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# interaction (excluding E/L mow differentiation)
mod.intYN = lm(SeedVol ~ MowYN + Warming + MowYN:Warming, data= data.new)
summary(mod.intYN)
```

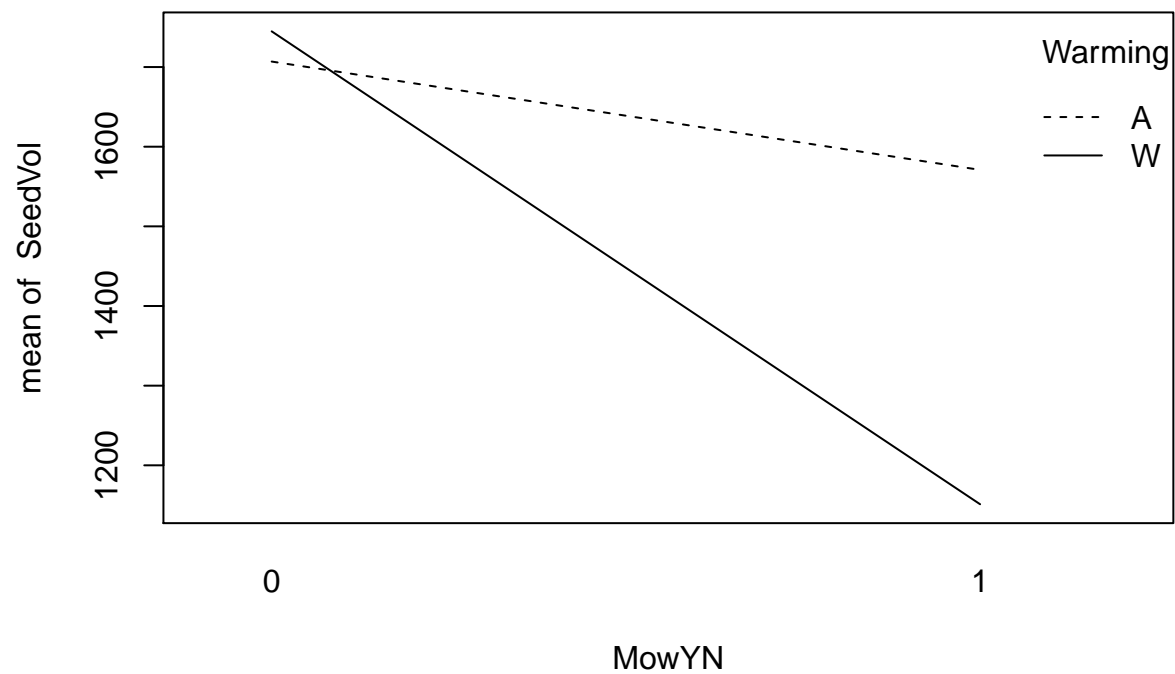
```
##
## Call:
## lm(formula = SeedVol ~ MowYN + Warming + MowYN:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1519.8  -598.5   -91.8    403.3   3525.8
##
```

```
## Coefficients:
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)   1706.90     103.25  16.531  <2e-16 ***
## MowYN         -135.99     128.66  -1.057   0.2912
## WarmingW       37.93     143.82   0.264   0.7922
## MowYN:WarmingW -457.71     178.28  -2.567   0.0106 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 819.5 on 369 degrees of freedom
## Multiple R-squared:  0.08437,    Adjusted R-squared:  0.07693
## F-statistic: 11.33 on 3 and 369 DF,  p-value: 3.969e-07
```

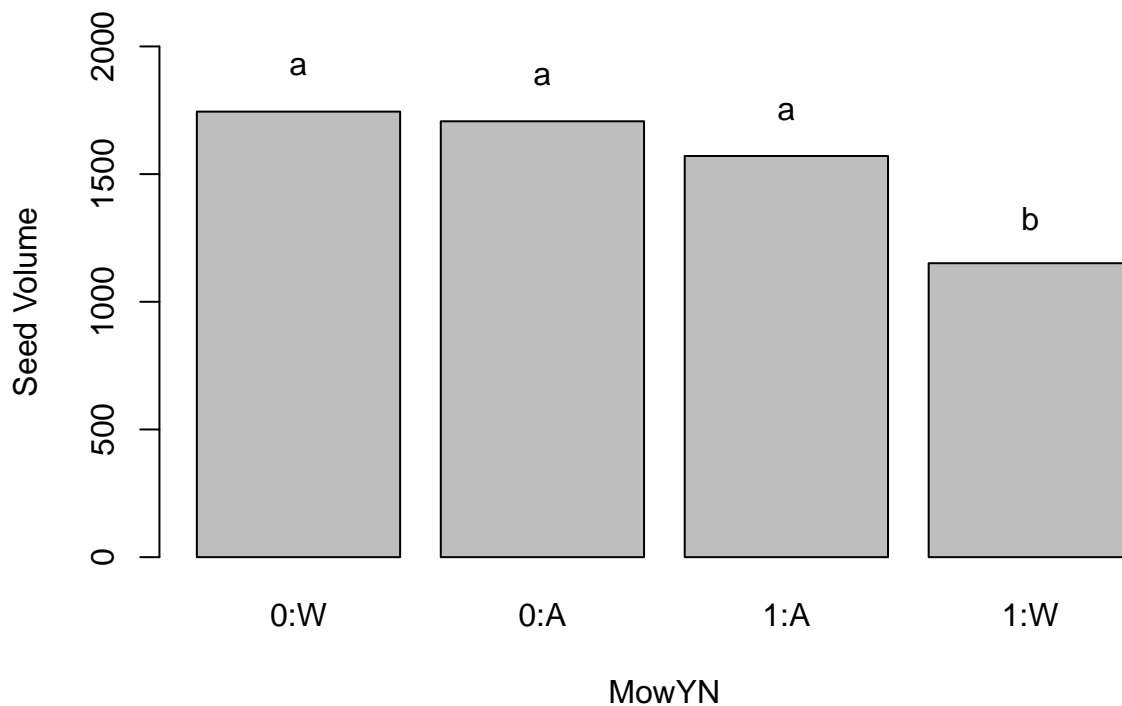
```
anova(mod.intYN)
```

```
## Analysis of Variance Table
##
## Response: SeedVol
##           Df      Sum Sq Mean Sq F value    Pr(>F)
## MowYN       1  12126046 12126046 18.0545 2.722e-05 ***
## Warming     1   6284163  6284163  9.3565 0.002384 **
## MowYN:Warming 1   4427083  4427083  6.5915 0.010640 *
## Residuals   369 247833497    671635
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
par(mfrow = c(1,1))
with(data.new, interaction.plot(x.factor = MowYN,Warming,response = SeedVol))
```



```
out = HSD.test(aov(SeedVol ~ MowYN + Warming + MowYN:Warming, data= data.new), c("MowYN", "Warming"))
bar.group(out$groups, ylim = c(0,2000), xlab = "MowYN", ylab = "Seed Volume")
```



```
# partial F test: compare full model to warming only model
anova(mod.mow, lm(SeedVol~MowYN + Warming, data = data.new), mod.intYN)
```

```
## Analysis of Variance Table
##
## Model 1: SeedVol ~ Mow
## Model 2: SeedVol ~ MowYN + Warming
## Model 3: SeedVol ~ MowYN + Warming + MowYN:Warming
##   Res.Df      RSS Df Sum of Sq    F Pr(>F)
## 1      370 257622187
## 2      370 252260579  0    5361608
## 3      369 247833497  1    4427083 6.5915 0.01064 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

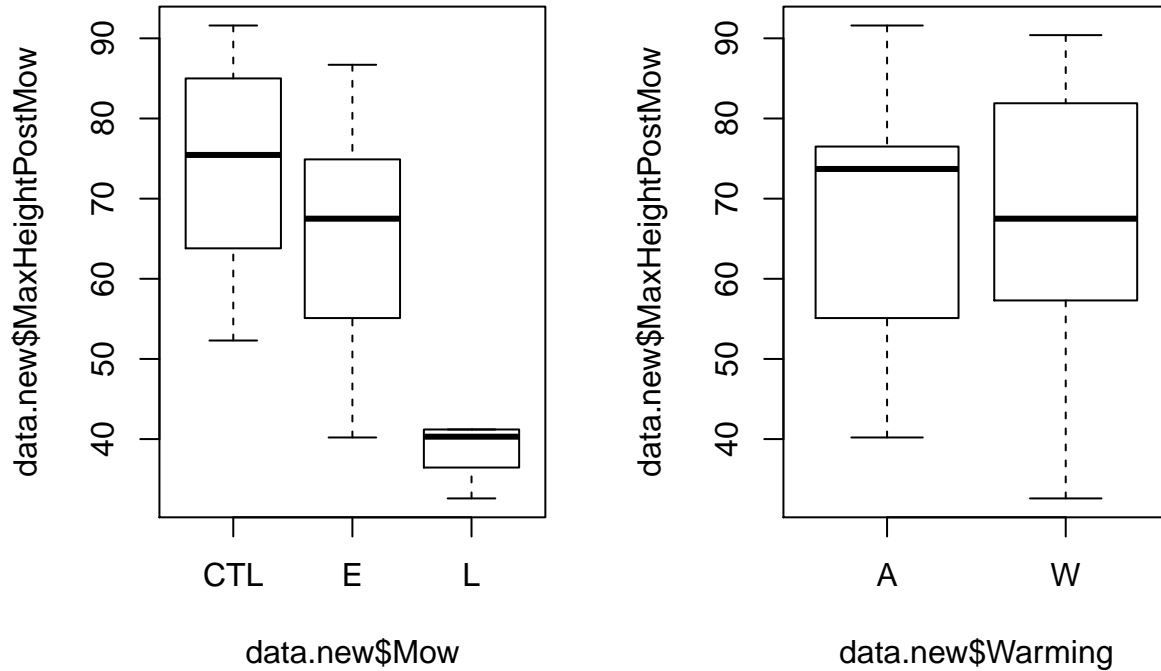
Conclusions:

1. The results for seed volume are very similar to those of seed width. Seed volume is decreased by both warming and mowing, though the seeds showing the strongest effect are both warmed and mowed.

Plant Height

Boxplot

```
# Warming and mowing vs. average DT
par(mfrow = c(1,2))
boxplot(data.new$MaxHeightPostMow ~ data.new$Mow)
boxplot(data.new$MaxHeightPostMow ~ data.new$Warming)
```

ANOVA: Warming and Mowing Alone

```
## ANOVA
# warming
mod.warm = lm(MaxHeightPostMow ~ Warming, data= data.new)
summary(mod.warm)

##
## Call:
## lm(formula = MaxHeightPostMow ~ Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -34.266 -11.737   5.734  10.063  24.763
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  66.8367    1.1135   60.022  <2e-16 ***
## WarmingW      0.0296    1.5361    0.019   0.985
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 14.81 on 371 degrees of freedom
## Multiple R-squared:  1.001e-06, Adjusted R-squared:  -0.002694
```

```
## F-statistic: 0.0003714 on 1 and 371 DF, p-value: 0.9846
# mowYN
mod.mowYN = lm(MaxHeightPostMow ~ MowYN, data= data.new)
summary(mod.mowYN)

##
## Call:
## lm(formula = MaxHeightPostMow ~ MowYN, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -30.777  -9.548   3.552  11.523  23.323
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   73.348     1.230   59.617 < 2e-16 ***
## MowYN         -9.970     1.524  -6.541 2.03e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 14.03 on 371 degrees of freedom
## Multiple R-squared:  0.1034, Adjusted R-squared:  0.101
## F-statistic: 42.78 on 1 and 371 DF, p-value: 2.03e-10
# early vs. late mowing
mod.mow = lm(MaxHeightPostMow ~ Mow, data= data.new)
summary(mod.mow)

##
## Call:
## lm(formula = MaxHeightPostMow ~ Mow, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -25.884  -8.784   1.415   8.816  20.616
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   73.348     1.086   67.524 < 2e-16 ***
## MowE          -7.263     1.371  -5.297 2.03e-07 ***
## MowL         -34.673     2.752 -12.601 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 12.39 on 370 degrees of freedom
## Multiple R-squared:  0.303, Adjusted R-squared:  0.2992
## F-statistic: 80.41 on 2 and 370 DF, p-value: < 2.2e-16
TukeyHSD(aov(MaxHeightPostMow ~ Mow, data= data.new))

## Tukey multiple comparisons of means
## 95% family-wise confidence level
##
## Fit: aov(formula = MaxHeightPostMow ~ Mow, data = data.new)
##
```

```
## $Mow
##           diff           lwr           upr p adj
## E-CTL -7.263217 -10.49004 -4.036396 6e-07
## L-CTL -34.672692 -41.14768 -28.197704 0e+00
## L-E -27.409475 -33.67607 -21.142883 0e+00
```

ANOVA: Warming and Mowing Multivariate

```
# interaction (including E/L mow differentiation)
```

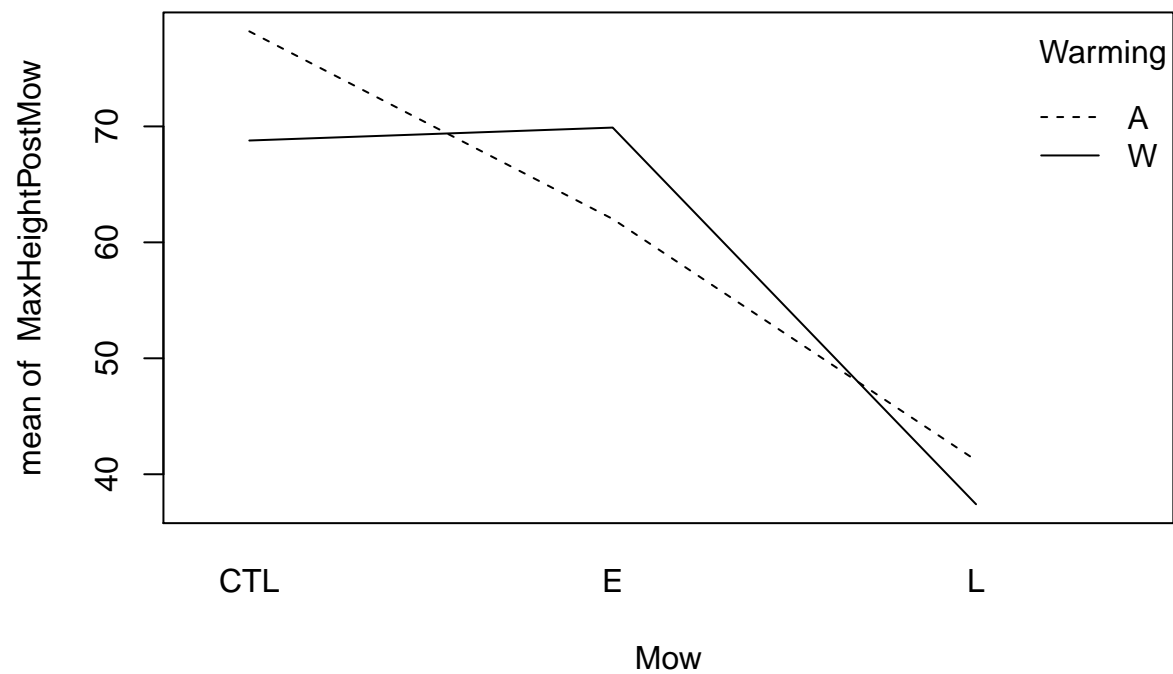
```
mod.int = lm(MaxHeightPostMow ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)
```

```
##
## Call:
## lm(formula = MaxHeightPostMow ~ Mow + Warming + Mow:Warming,
##     data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -23.599  -6.918  -1.300   12.001   21.615
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)      78.200      1.476   52.964 < 2e-16 ***
## MowE             -16.182      1.864   -8.680 < 2e-16 ***
## MowL             -37.000      4.399   -8.412 9.09e-16 ***
## WarmingW          -9.415      2.057   -4.578 6.44e-06 ***
## MowE:WarmingW     17.296      2.596    6.662 9.91e-11 ***
## MowL:WarmingW      5.627      5.475    1.028  0.305
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 11.72 on 367 degrees of freedom
## Multiple R-squared:  0.381, Adjusted R-squared:  0.3725
## F-statistic: 45.17 on 5 and 367 DF, p-value: < 2.2e-16
```

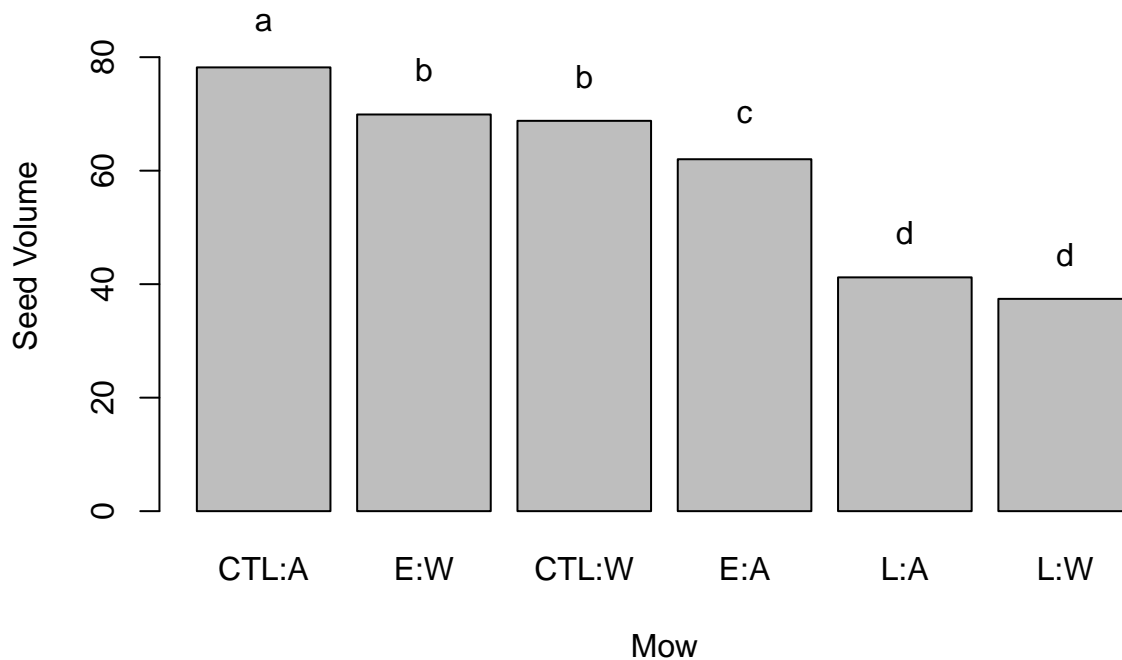
```
anova(mod.int)
```

```
## Analysis of Variance Table
##
## Response: MaxHeightPostMow
##           Df Sum Sq Mean Sq F value    Pr(>F)
## Mow         2  24669 12334.4  89.8111 < 2.2e-16 ***
## Warming      1    120   119.6   0.8705  0.3514
## Mow:Warming  2   6232  3116.1  22.6896 5.12e-10 ***
## Residuals  367  50403   137.3
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
par(mfrow = c(1,1))
with(data.new, interaction.plot(x.factor = Mow,Warming,response = MaxHeightPostMow))
```



```
out = HSD.test(aov(MaxHeightPostMow ~ Mow + Warming + Mow:Warming, data= data.new), c("Mow","Warming"))
bar.group(out$groups, ylim = c(0,90), xlab = "Mow", ylab = "Seed Volume")
```



```
# partial F test: compare full model to warming only model
anova(mod.mow, lm(MaxHeightPostMow~Mow + Warming, data = data.new), mod.int)
```

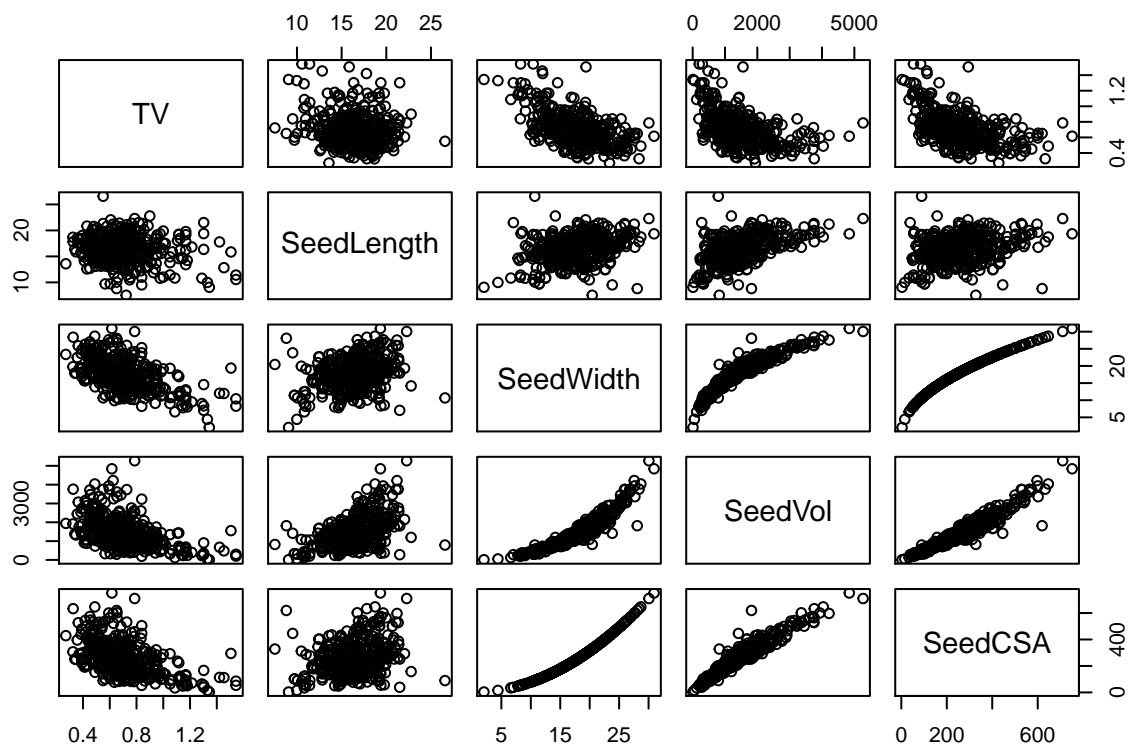
```
## Analysis of Variance Table
##
## Model 1: MaxHeightPostMow ~ Mow
## Model 2: MaxHeightPostMow ~ Mow + Warming
## Model 3: MaxHeightPostMow ~ Mow + Warming + Mow:Warming
##   Res.Df  RSS Df Sum of Sq    F    Pr(>F)
## 1      370 56755
## 2      369 56635   1    119.6  0.8705  0.3514
## 3      367 50403   2    6232.3 22.6896 5.12e-10 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conclusions:

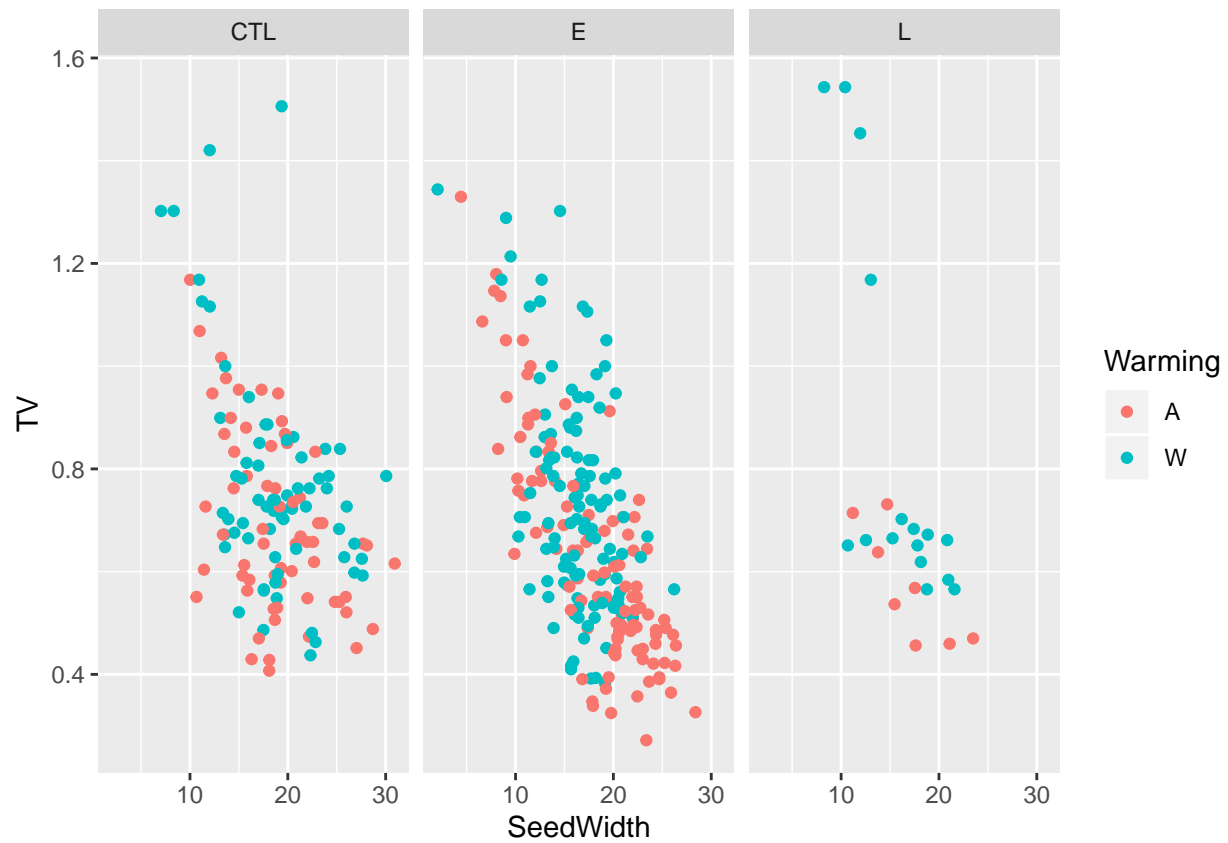
1. Mowing significantly reduces plant height. Warming allows early mowed plants to reach similar heights as the warmed control plants. There is no significant difference between late mowed plants by warming. Non-mowed ambient plants are taller than non-mowed warmed plants.

Is Terminal Velocity predicted by seed shape parameters?

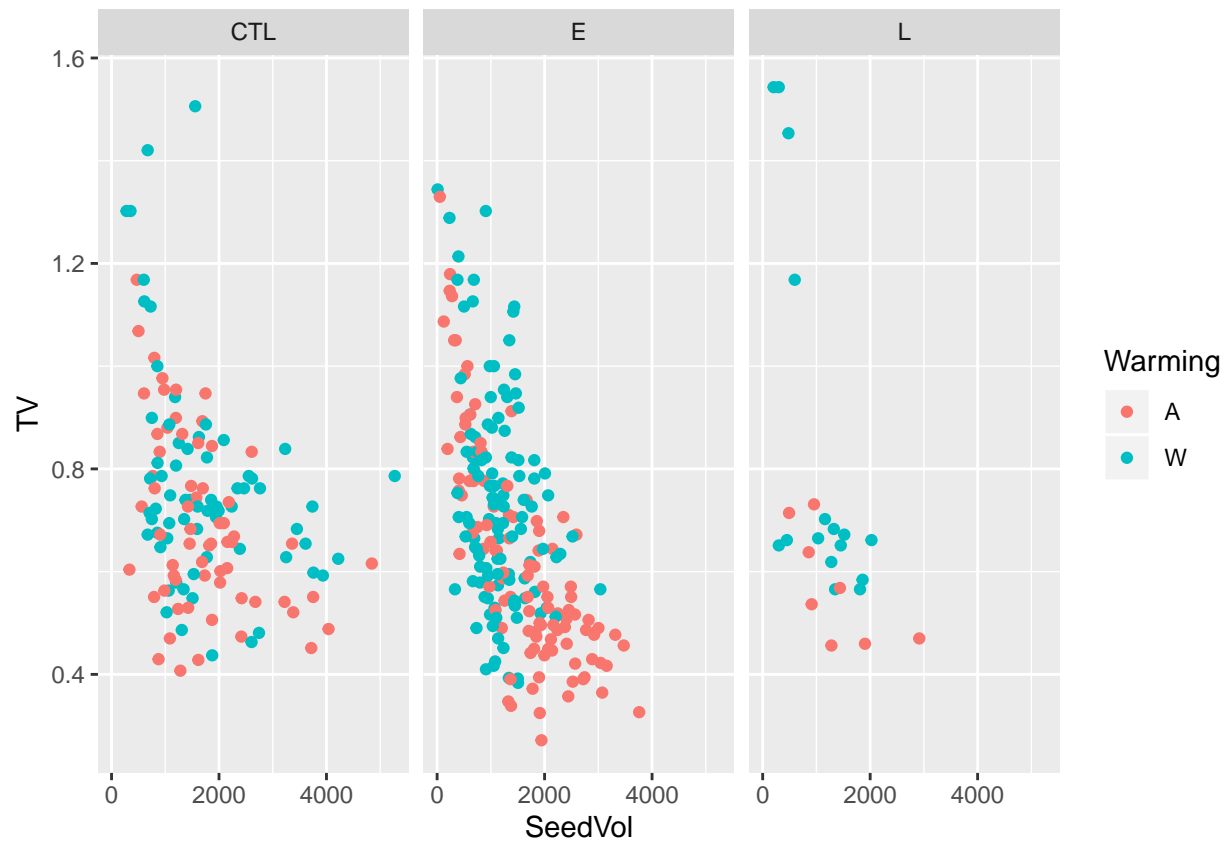
```
# Potential Predictors
pairs(data.new[,c("TV", "SeedLength", "SeedWidth", "SeedVol", "SeedCSA")])
```



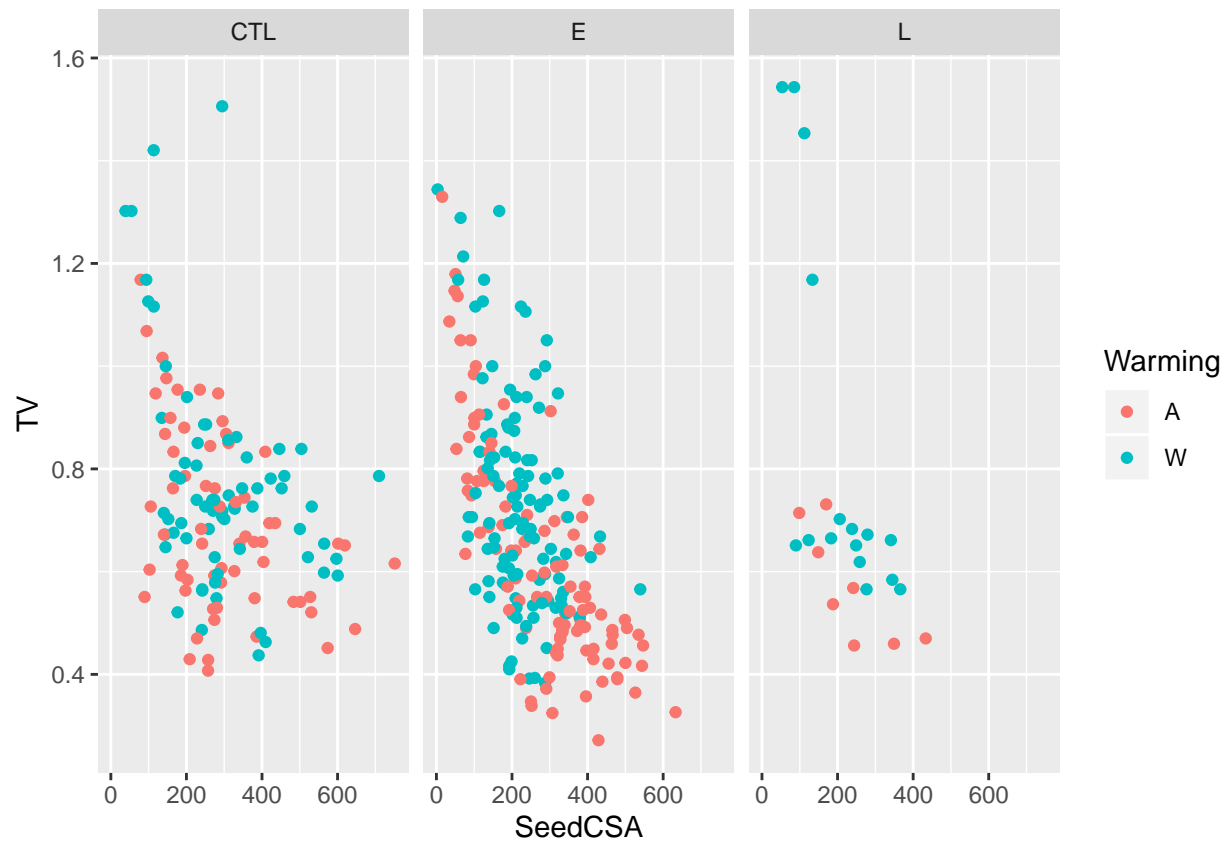
```
# plot TV vs. seed width by treatment
ggplot(data = data.new, aes(x = SeedWidth, y = TV, color = Warming)) +
  geom_point() +
  facet_wrap(data.new$Mow)
```



```
# plot TV vs. seed volume by treatment
ggplot(data = data.new, aes(x = SeedVol, y = TV, color = Warming))+
  geom_point()+
  facet_wrap(data.new$Mow)
```

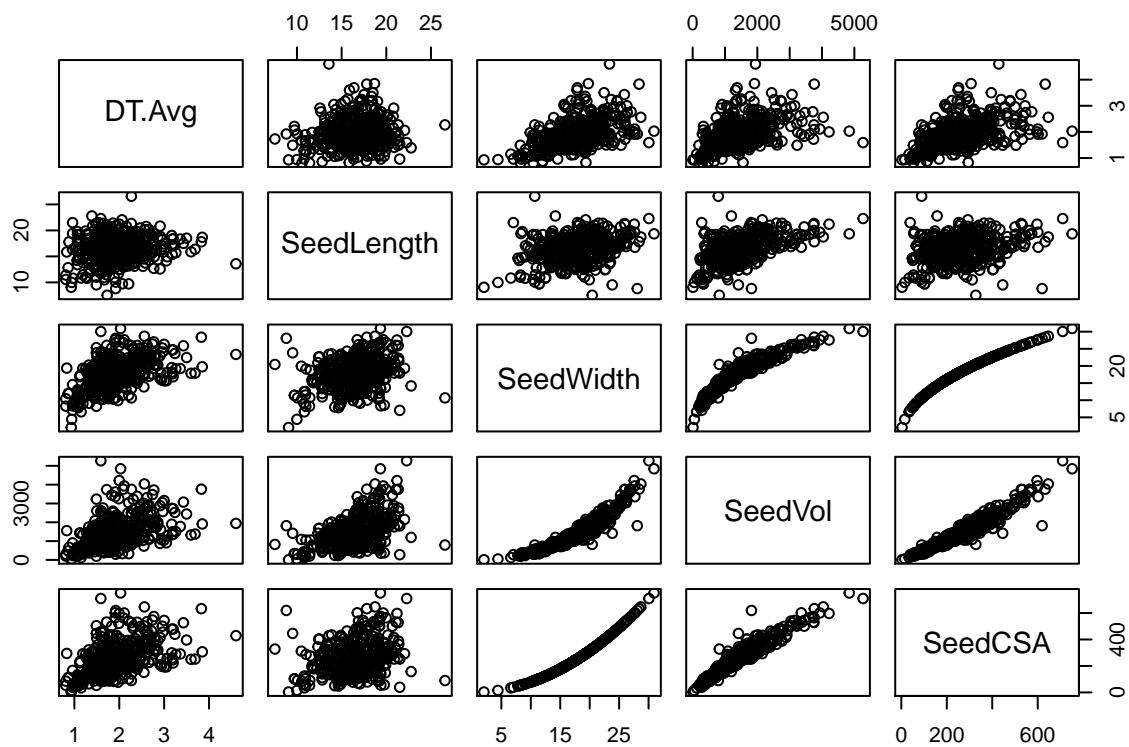


```
# plot TV vs. seed CSA by treatment
ggplot(data = data.new, aes(x = SeedCSA, y = TV, color = Warming))+
  geom_point()+
  facet_wrap(data.new$Mow)
```

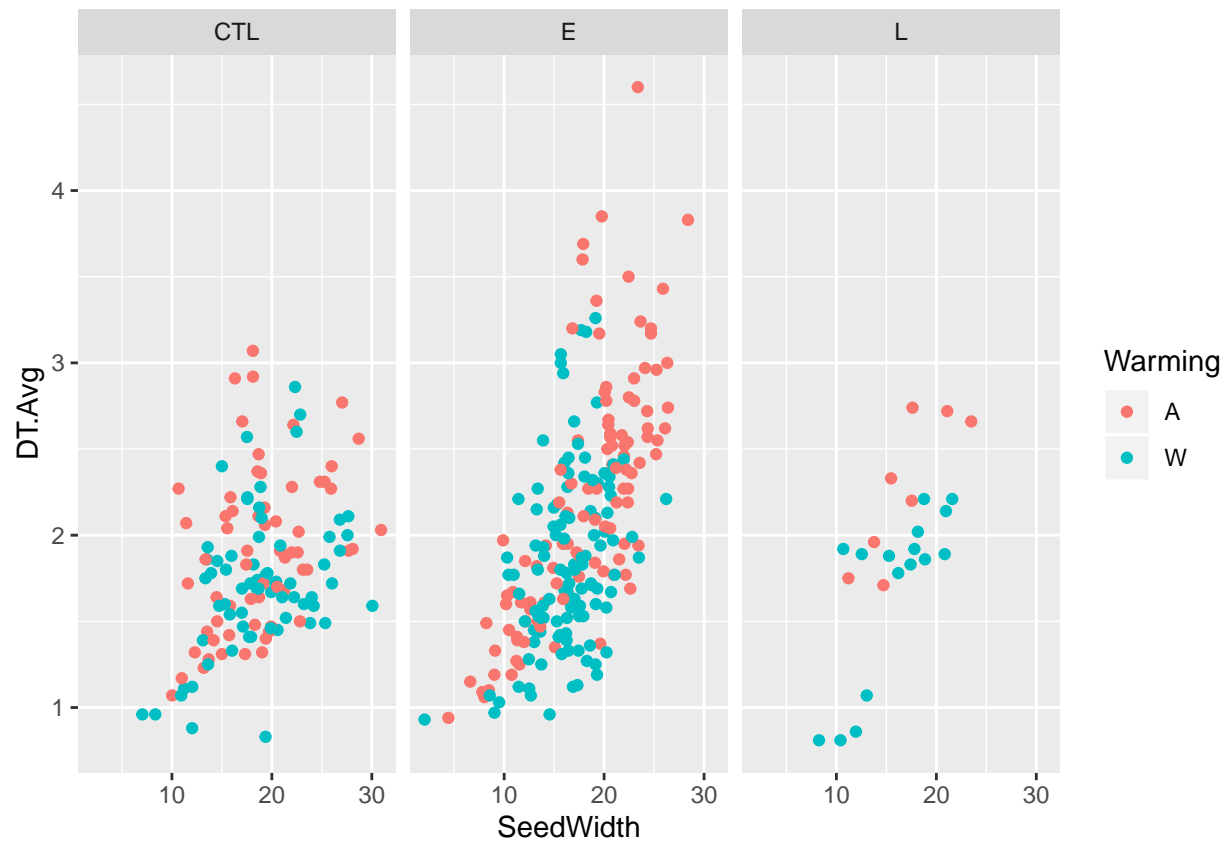



Is drop time predicted by seed shape parameters?

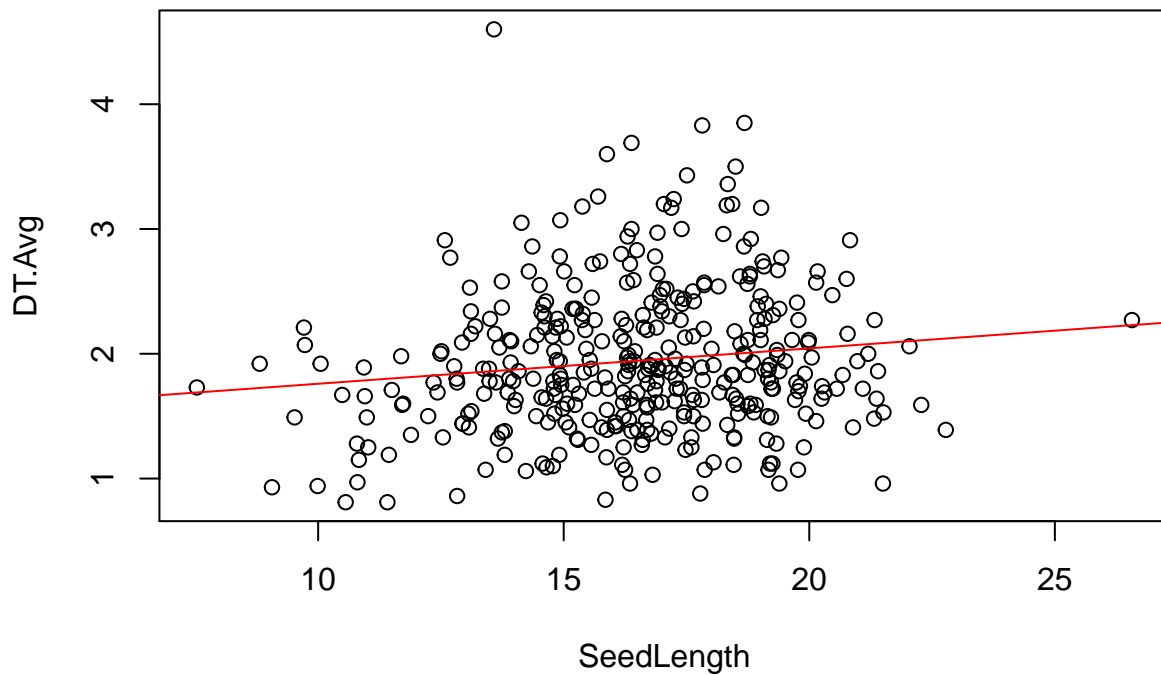
```
# Potential Predictors
pairs(data.new[,c("DT.Avg", "SeedLength", "SeedWidth", "SeedVol", "SeedCSA")])
```



```
# plot DT vs. seed width by treatment
ggplot(data = data.new, aes(x = SeedWidth, y = DT.Avg, color = Warming))+
  geom_point()+
  facet_wrap(data.new$Mow)
```



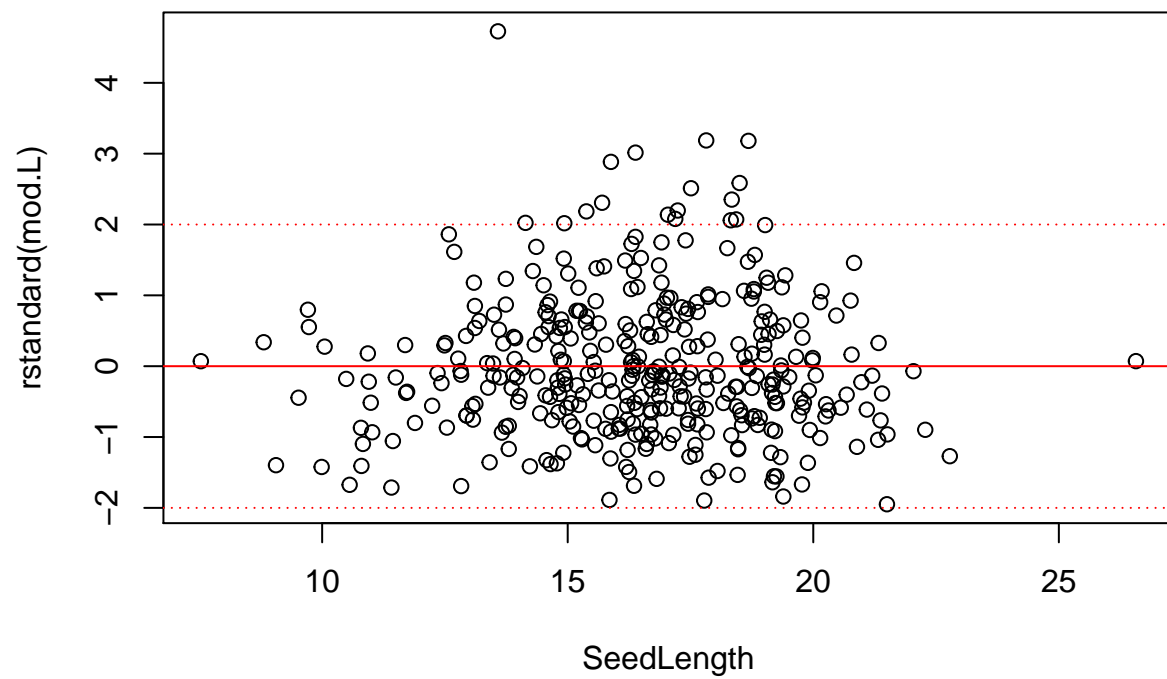
```
# Average DT ~ pappus length
mod.L <- lm(DT.Avg ~ SeedLength, data = data.new)
plot(DT.Avg ~ SeedLength, data = data.new)
abline(mod.L, col = "red")
```



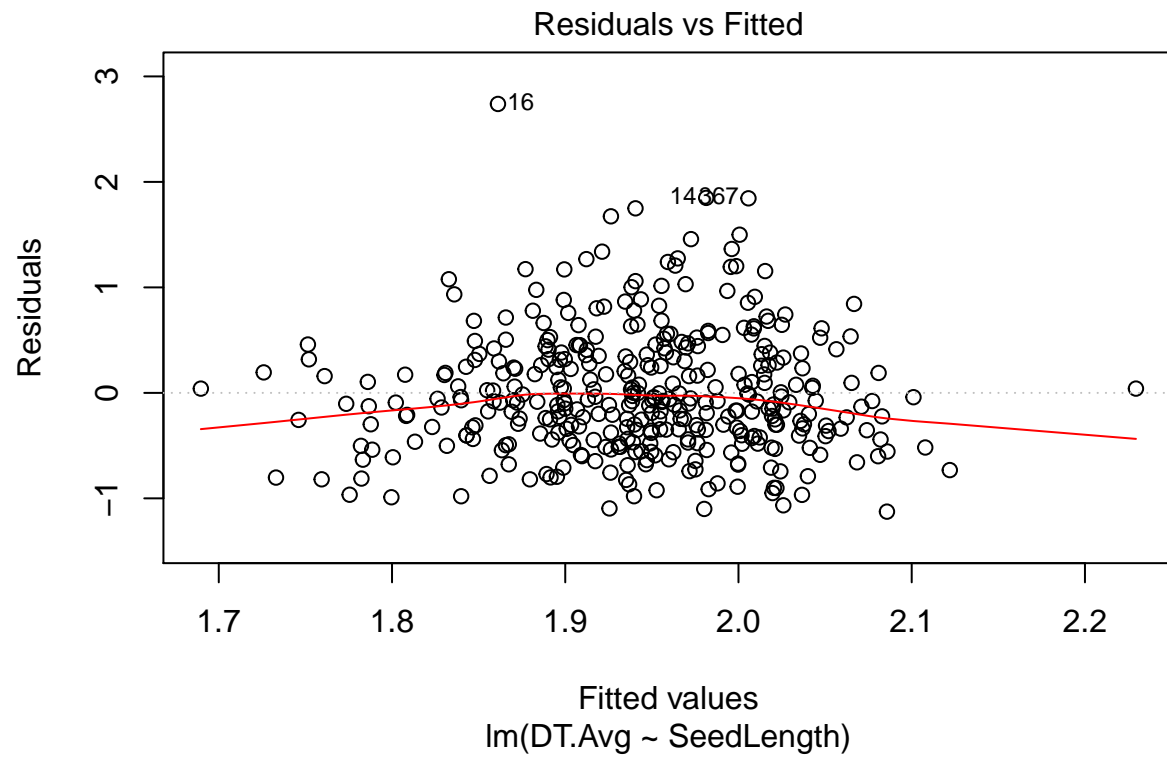
```
summary(mod.L)
```

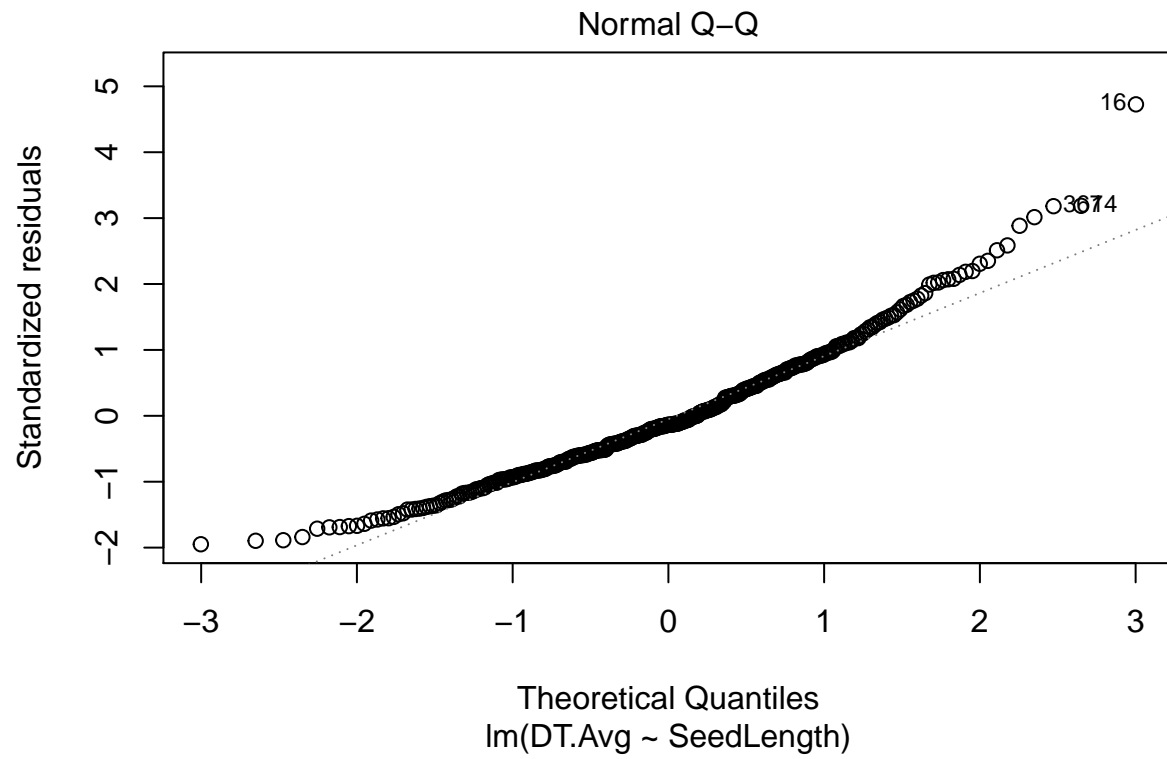
```
##
## Call:
## lm(formula = DT.Avg ~ SeedLength, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.12571 -0.40302 -0.07861  0.34512  2.73883
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.47616    0.18399   8.023 1.37e-14 ***
## SeedLength   0.02835    0.01103   2.569  0.0106 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5811 on 371 degrees of freedom
## Multiple R-squared:  0.01748,    Adjusted R-squared:  0.01483
## F-statistic: 6.601 on 1 and 371 DF,  p-value: 0.01058

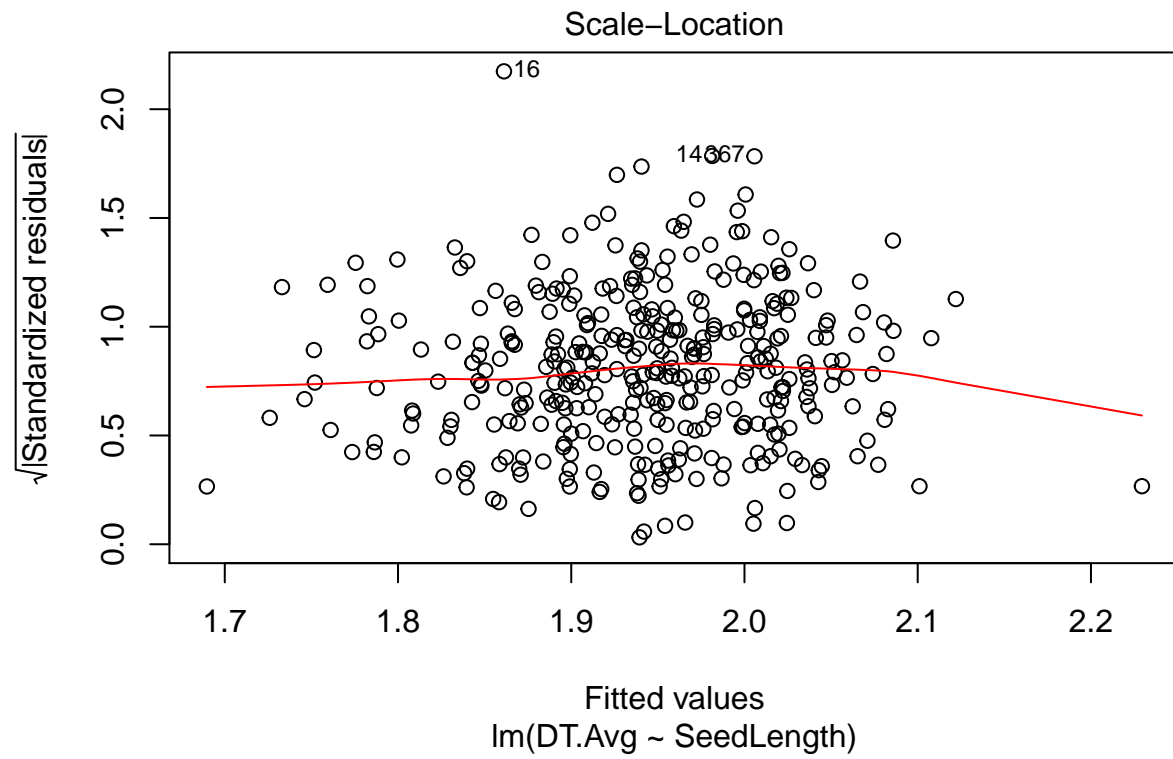
plot(rstandard(mod.L) ~ SeedLength, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```

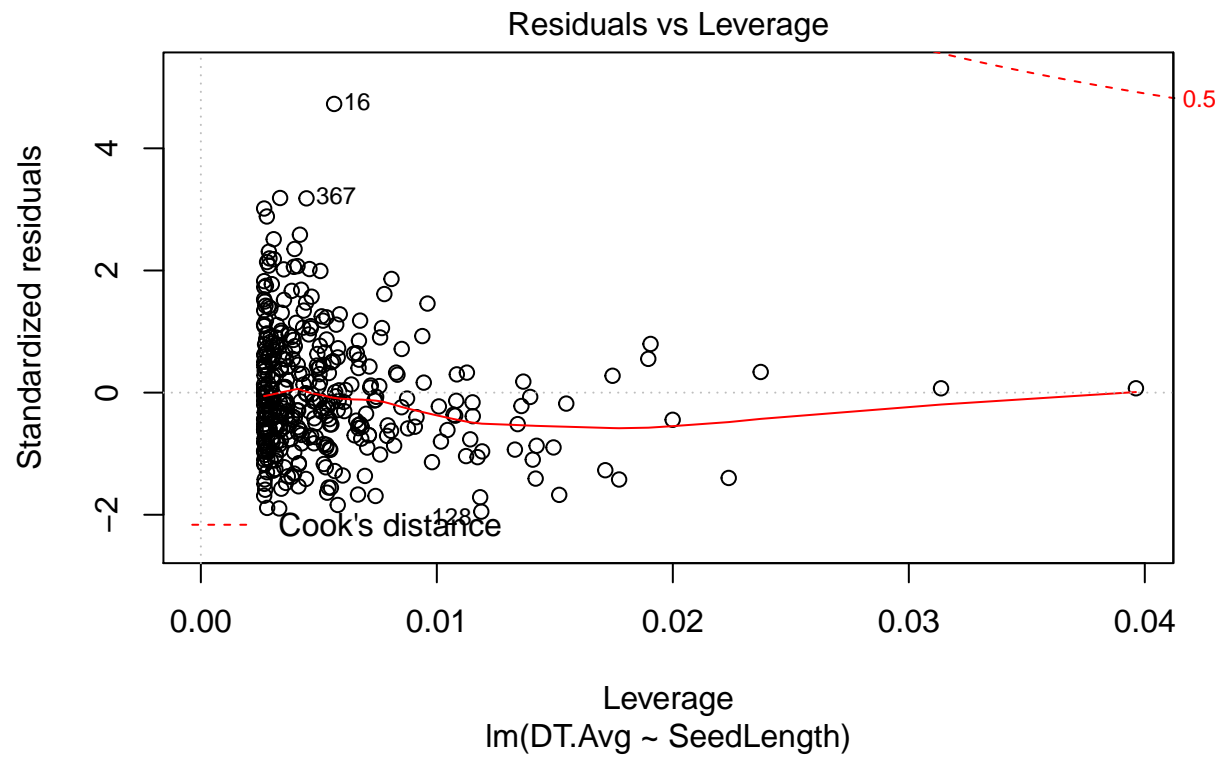


```
plot(mod.L, panel = panel.smooth)
```

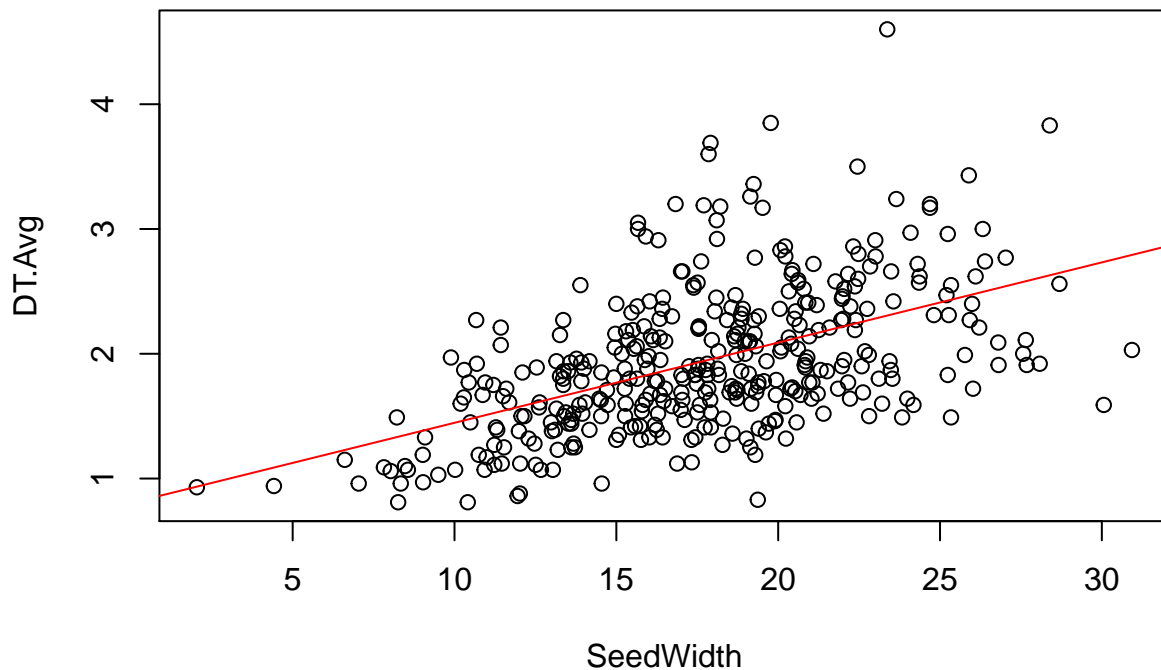








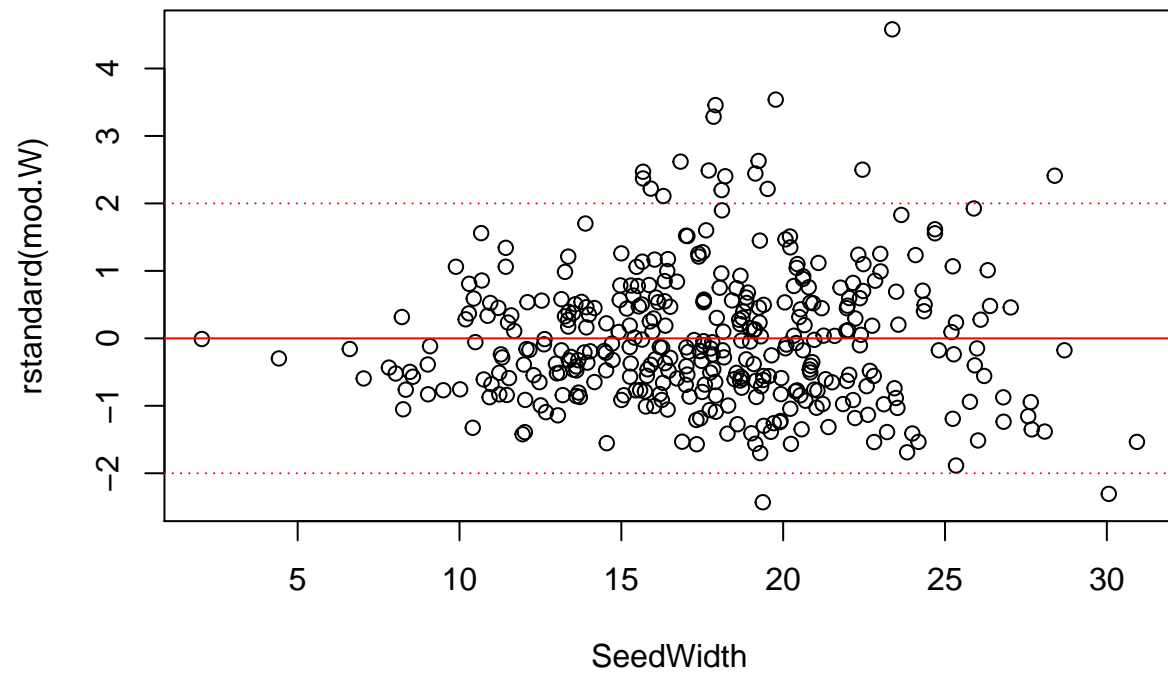
```
# Average DT ~ pappus width
mod.W <- lm(DT.Avg ~ SeedWidth, data = data.new)
plot(DT.Avg ~ SeedWidth, data = data.new)
abline(mod.W, col = "red")
```



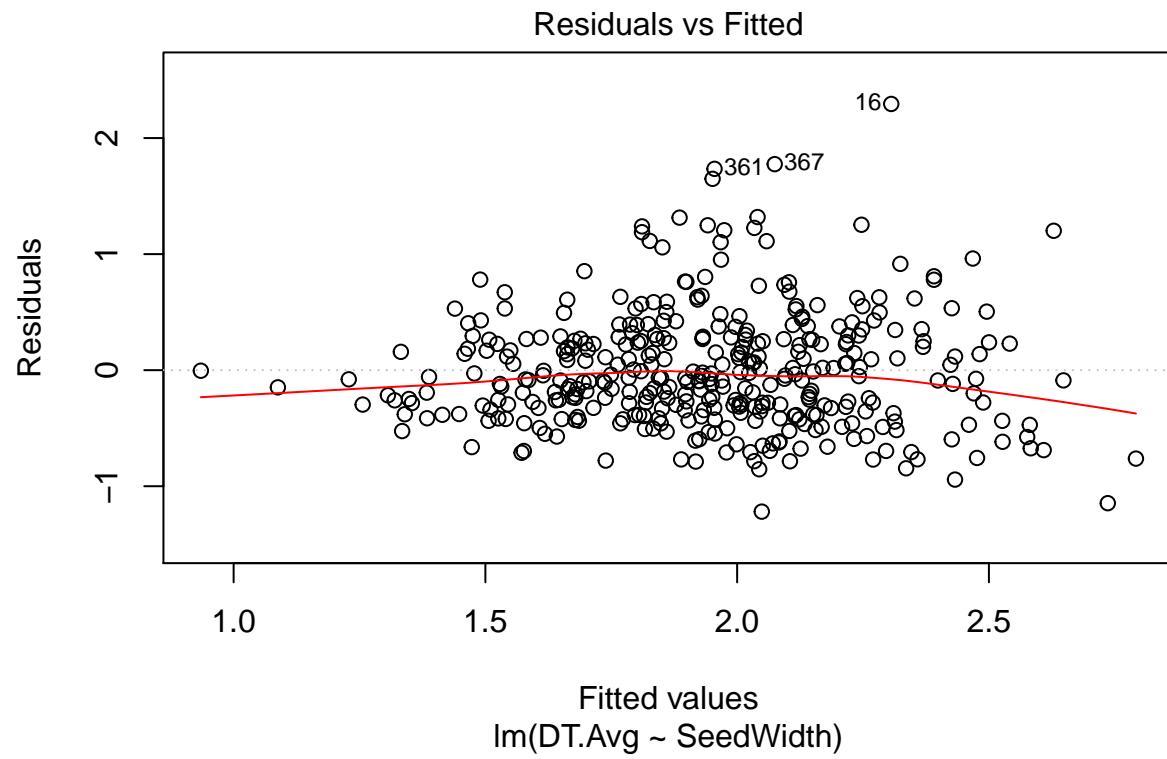
```
summary(mod.W)
```

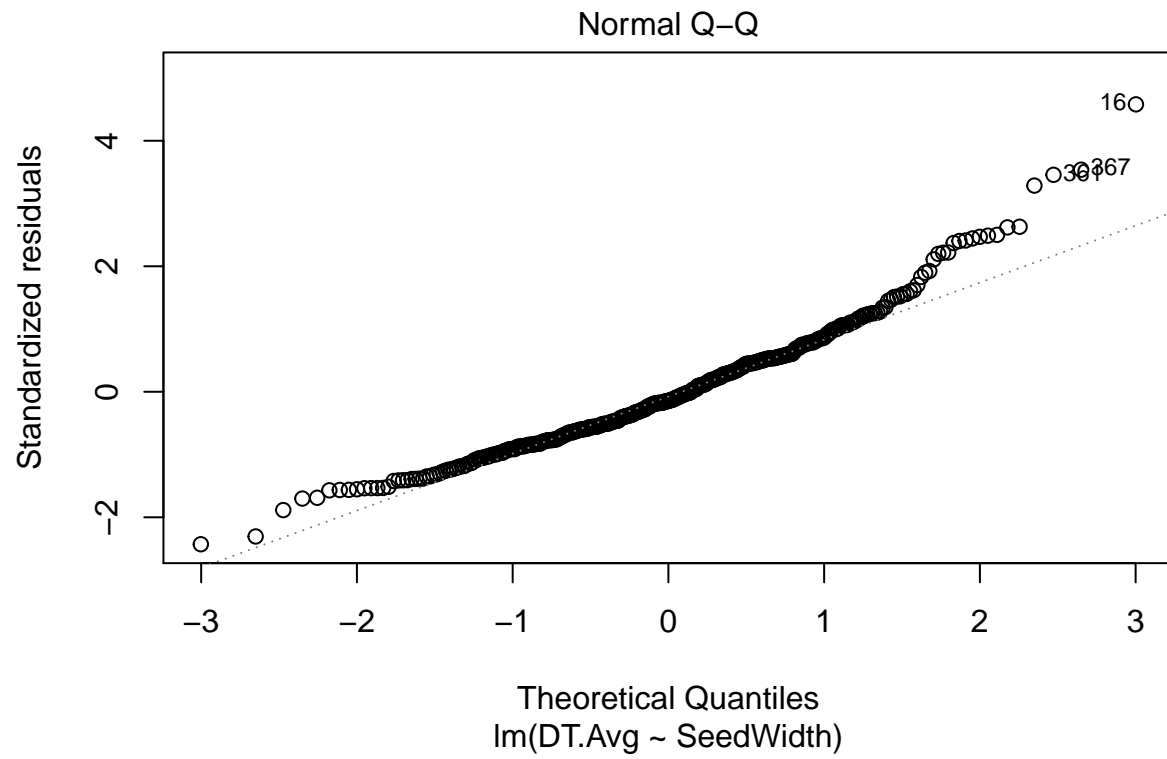
```
##
## Call:
## lm(formula = DT.Avg ~ SeedWidth, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.21893 -0.34594 -0.07393  0.26870  2.29394
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.803773   0.101777   7.897 3.26e-14 ***
## SeedWidth    0.064283   0.005555  11.573 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5025 on 371 degrees of freedom
## Multiple R-squared:  0.2653, Adjusted R-squared:  0.2633
## F-statistic: 133.9 on 1 and 371 DF, p-value: < 2.2e-16

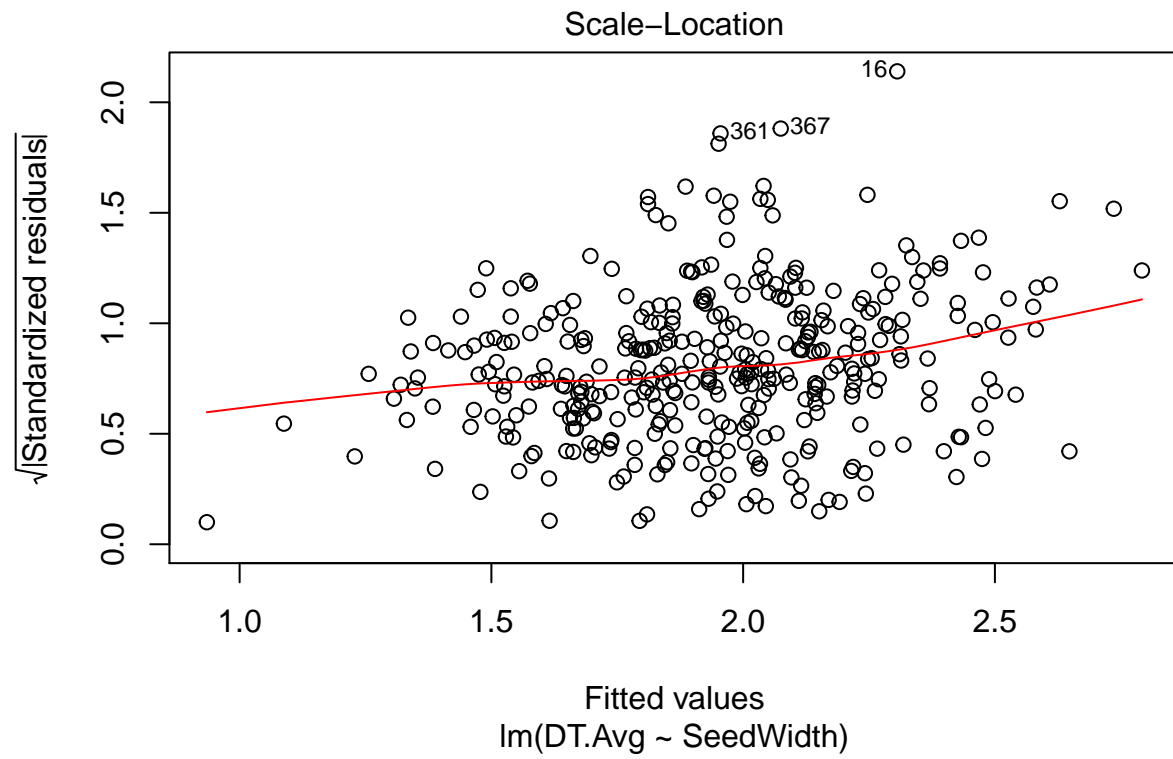
plot(rstandard(mod.W) ~ SeedWidth, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```

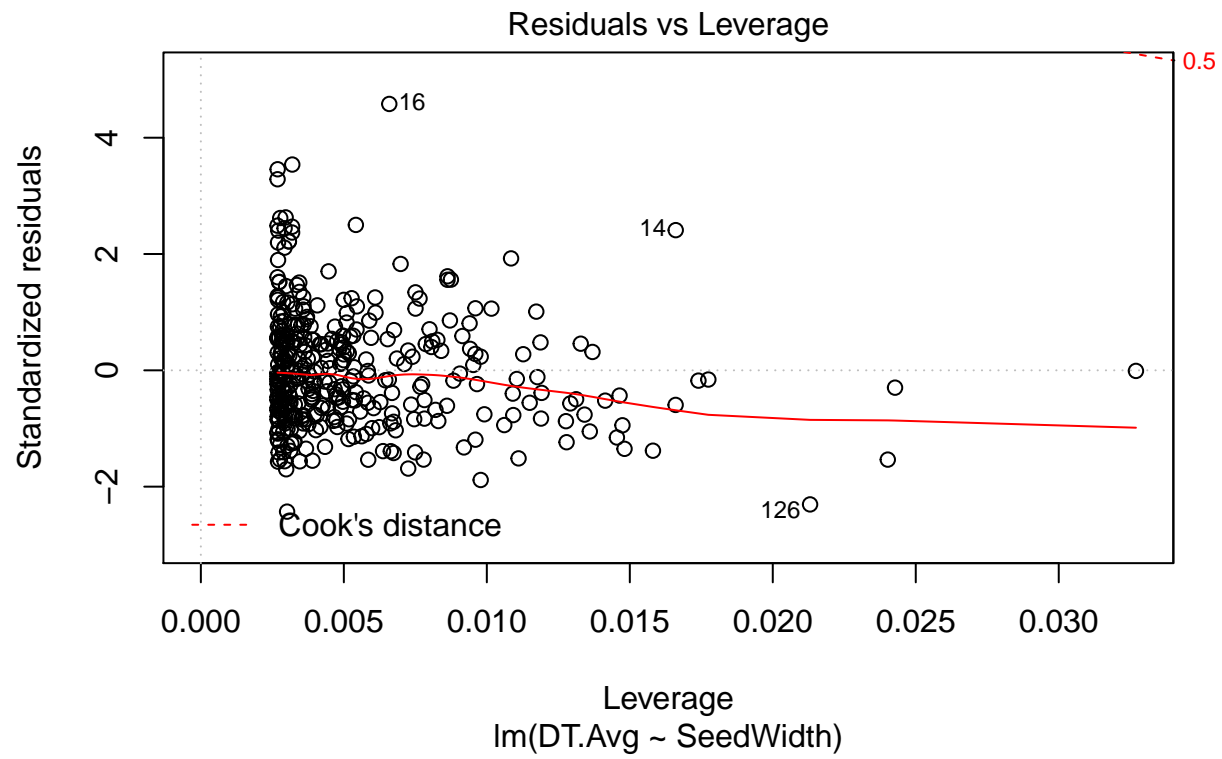


```
plot(mod.W)
```

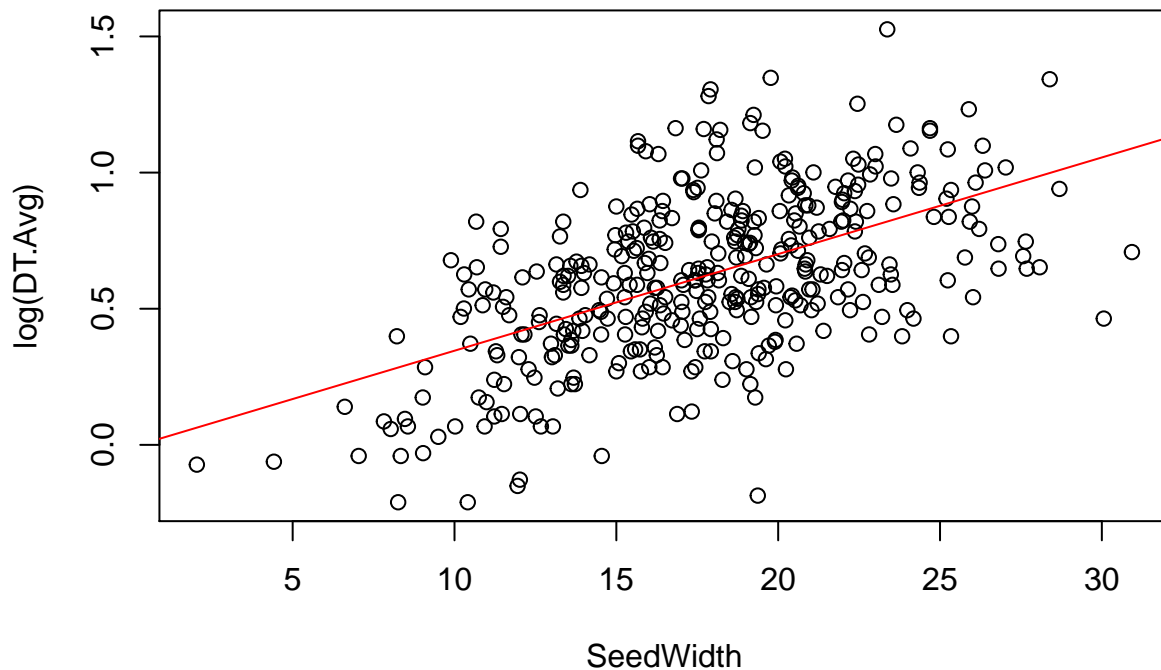








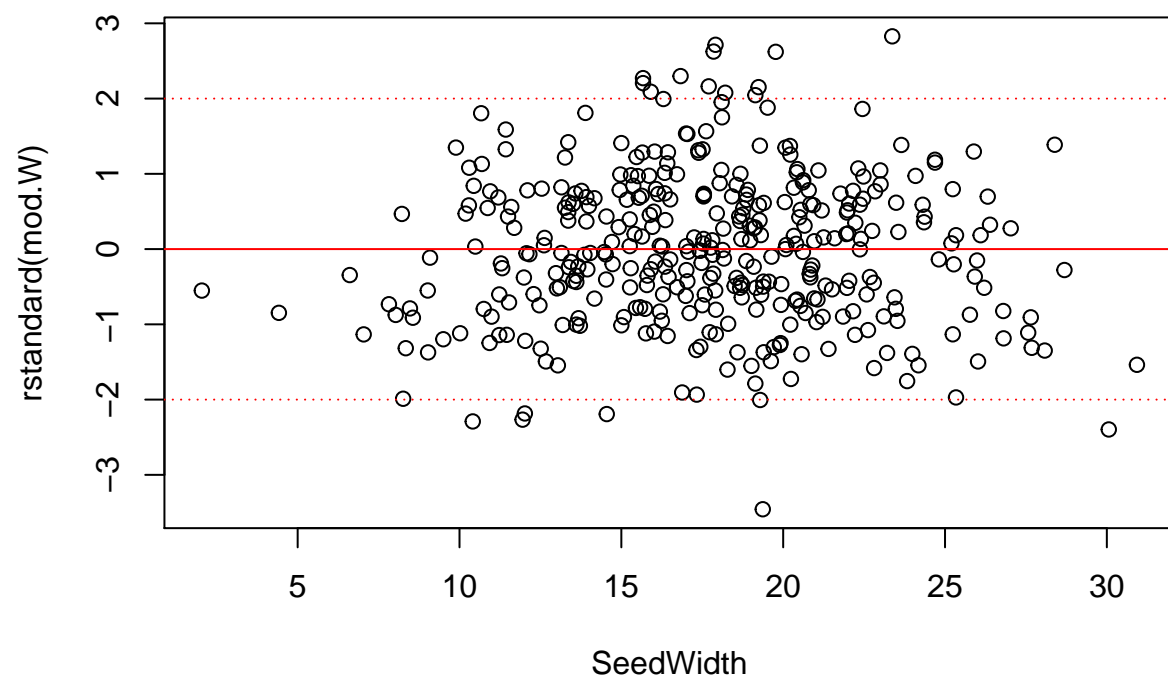
```
# Log-transformed average DT ~ pappus width
mod.W <- lm(log(DT.Avg) ~ SeedWidth, data = data.new)
plot(log(DT.Avg) ~ SeedWidth, data = data.new)
abline(mod.W, col = "red")
```



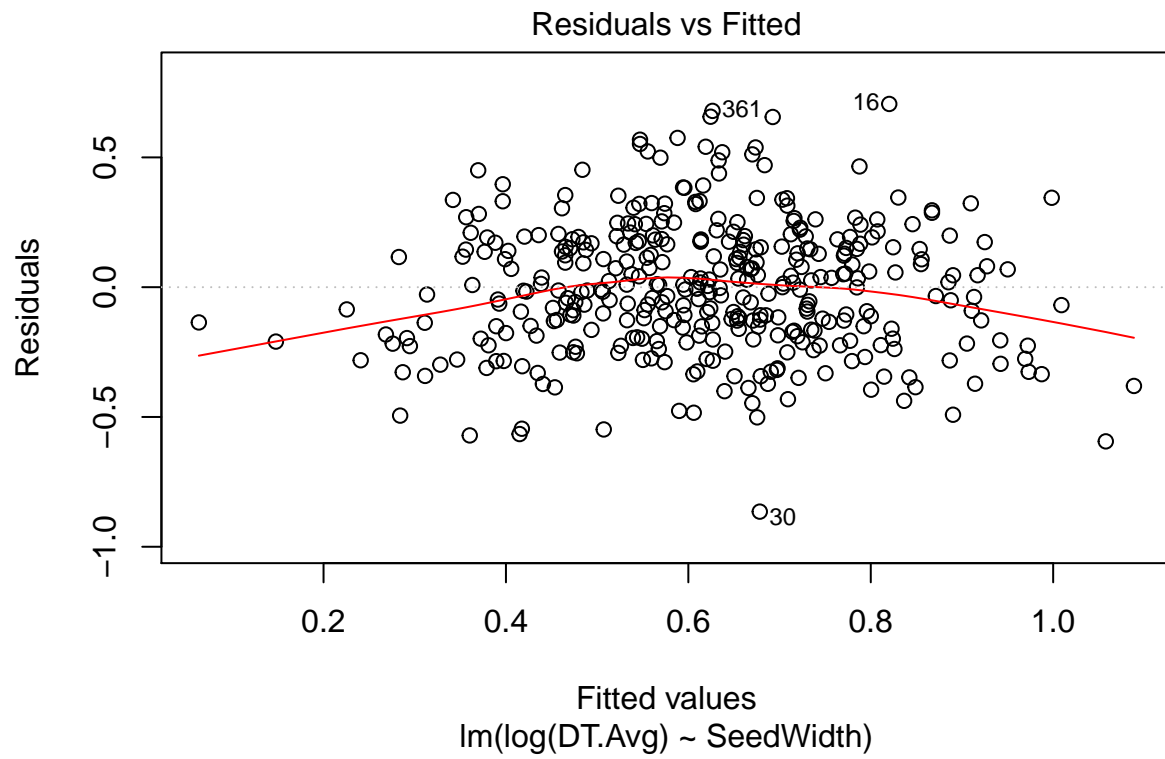
```
summary(mod.W)
```

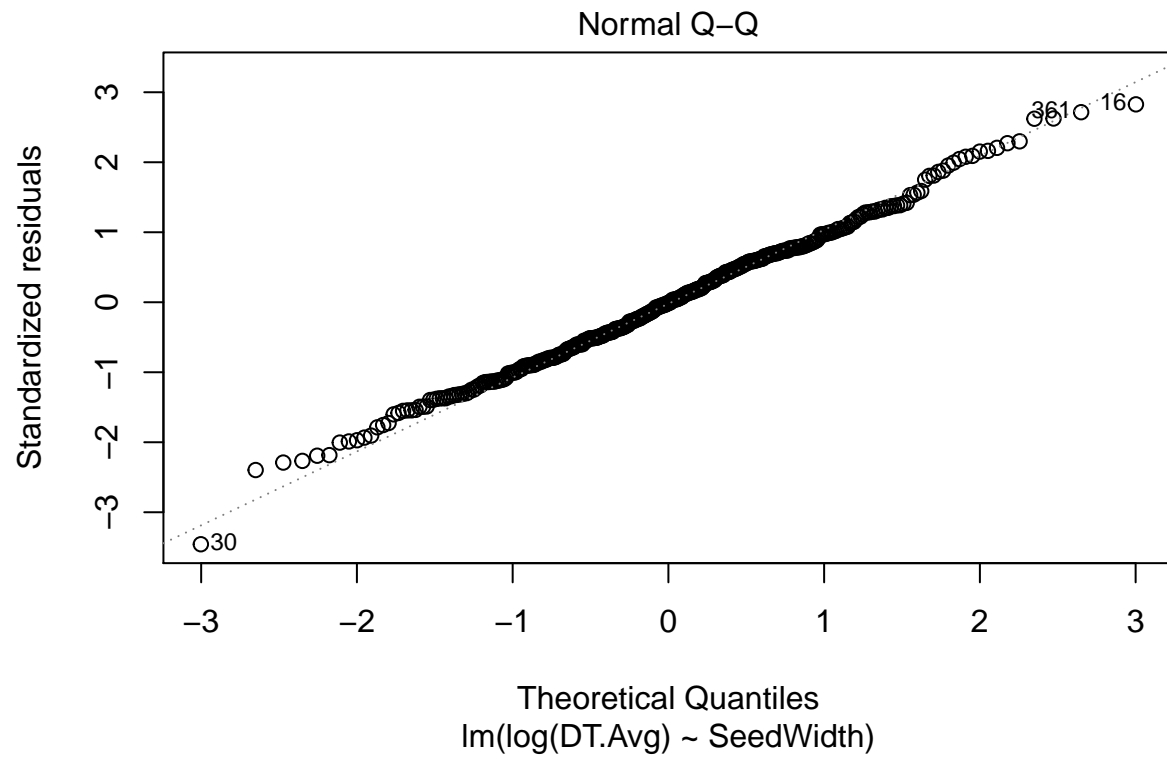
```
##
## Call:
## lm(formula = log(DT.Avg) ~ SeedWidth, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.86464 -0.18224 -0.00303  0.17262  0.70579
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.009110   0.050732  -0.18   0.858
## SeedWidth    0.035489   0.002769  12.82 <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2505 on 371 degrees of freedom
## Multiple R-squared:  0.3069, Adjusted R-squared:  0.3051
## F-statistic: 164.3 on 1 and 371 DF,  p-value: < 2.2e-16

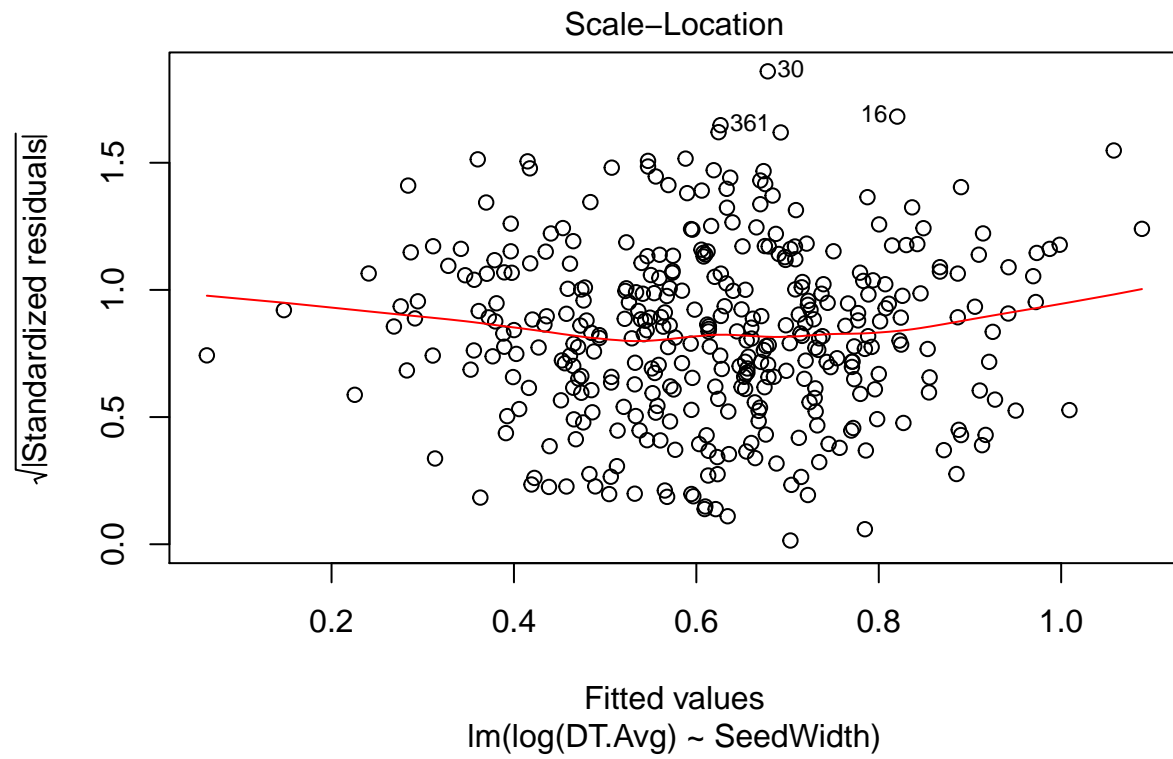
plot(rstandard(mod.W) ~ SeedWidth, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```

```
plot(mod.W)
```

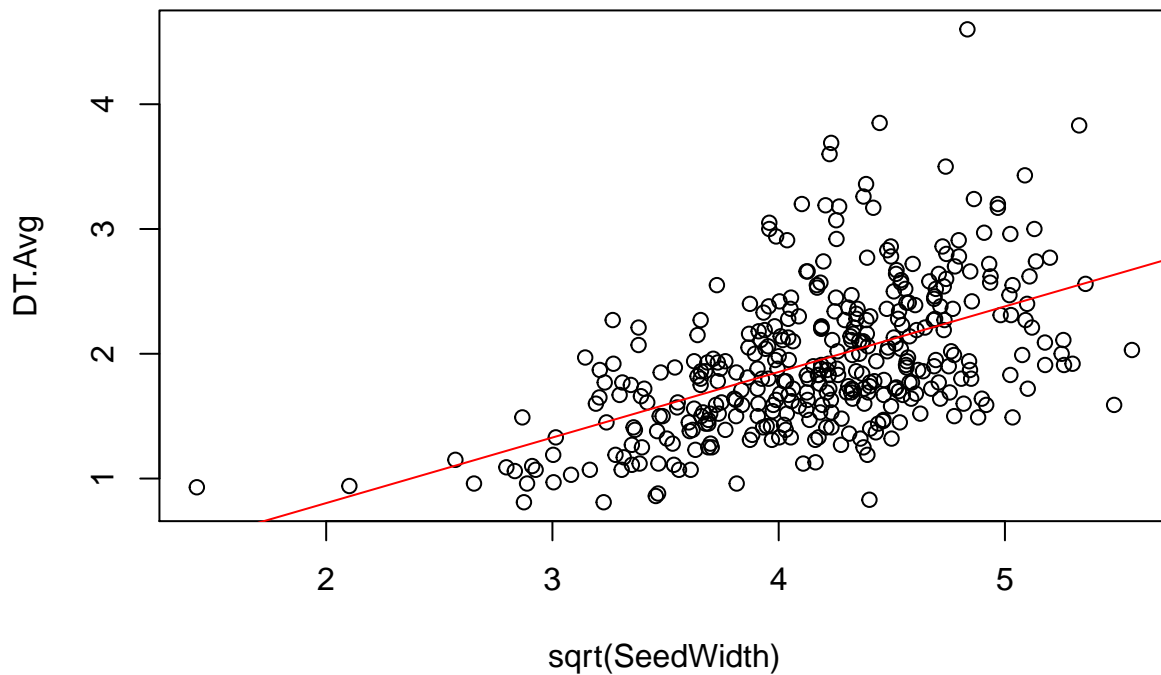








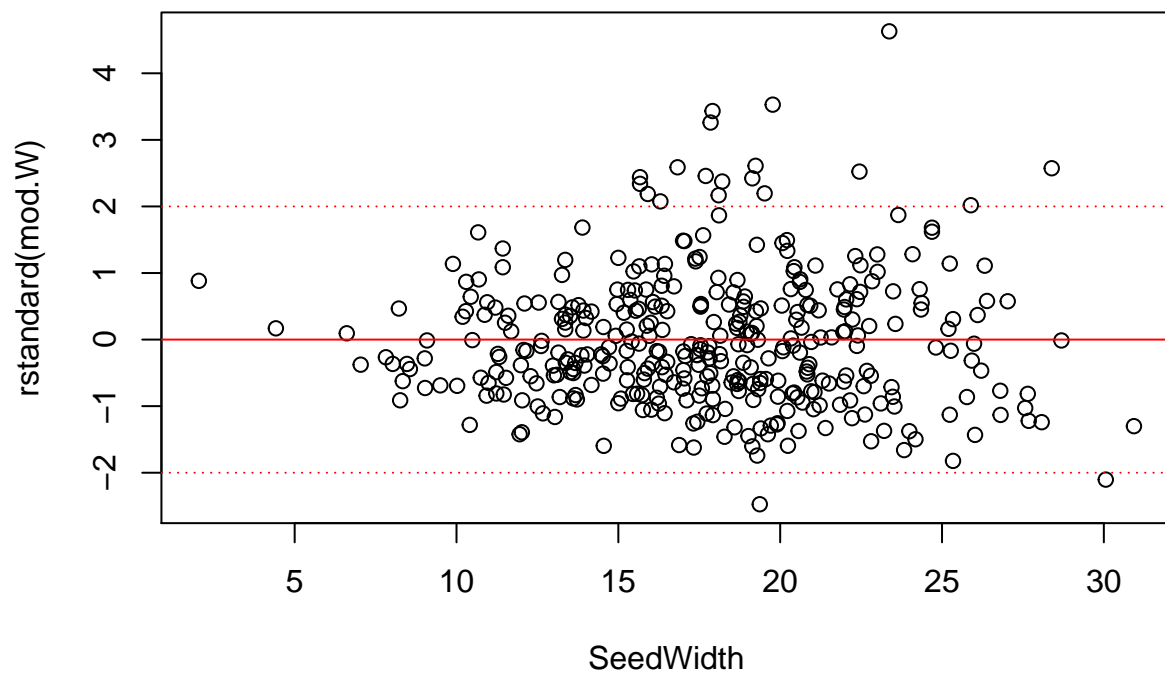
```
# Square-root average DT ~ pappus width
mod.W <- lm(DT.Avg ~ sqrt(SeedWidth), data = data.new)
plot(DT.Avg ~ sqrt(SeedWidth), data = data.new)
abline(mod.W, col = "red")
```



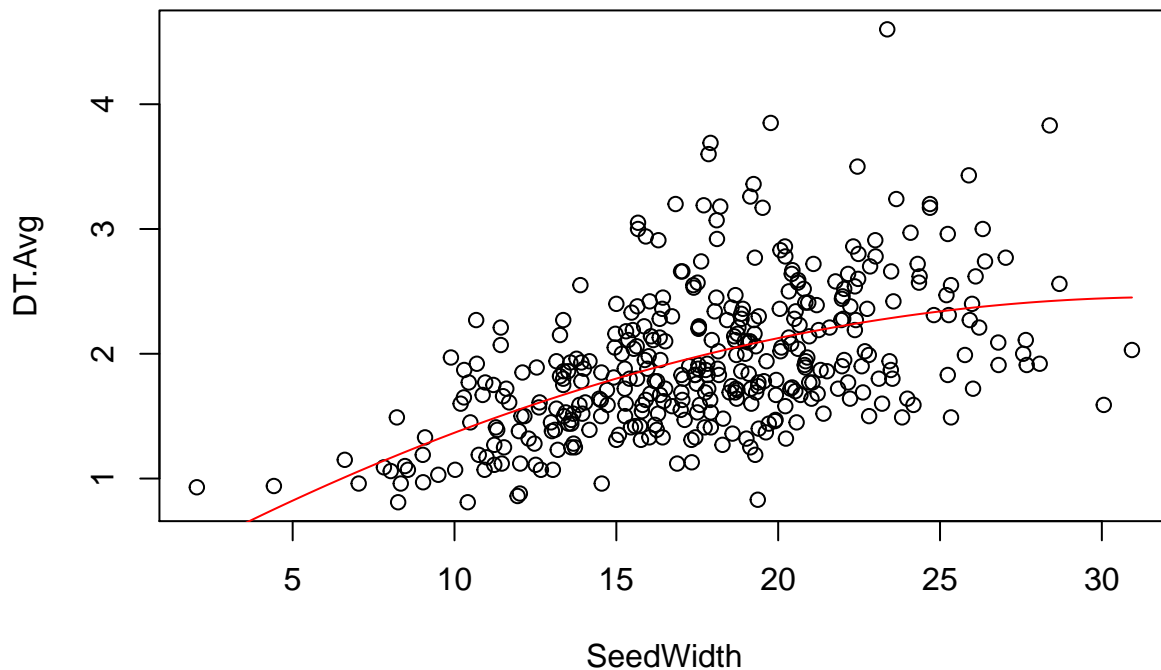
```
summary(mod.W)
```

```
##
## Call:
## lm(formula = DT.Avg ~ sqrt(SeedWidth), data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.23470 -0.34549 -0.07214  0.26617  2.30774
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -0.24758    0.18751   -1.32   0.188
## sqrt(SeedWidth)  0.52538    0.04455   11.79  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5 on 371 degrees of freedom
## Multiple R-squared:  0.2727, Adjusted R-squared:  0.2707
## F-statistic: 139.1 on 1 and 371 DF, p-value: < 2.2e-16

plot(rstandard(mod.W) ~ SeedWidth, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```



```
# Average DT ~ pappus width only (w/ quadratic term)
mod.W2 <- lm(DT.Avg ~ SeedWidth + I(SeedWidth^2), data = data.new)
plot(DT.Avg ~ SeedWidth, data = data.new)
curve(predict(mod.W2, newdata = data.frame(SeedWidth = x)), add = T, col = "red")
```



```
summary(mod.W2)
```

```
##
## Call:
## lm(formula = DT.Avg ~ SeedWidth + I(SeedWidth^2), data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.26051 -0.34955 -0.06896  0.25893  2.31826
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.1688639   0.2615306    0.646  0.51889
## SeedWidth     0.1418079   0.0299689    4.732 3.17e-06 ***
## I(SeedWidth^2) -0.0021993   0.0008357   -2.632  0.00885 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4985 on 370 degrees of freedom
## Multiple R-squared:  0.2788, Adjusted R-squared:  0.2749
## F-statistic: 71.5 on 2 and 370 DF, p-value: < 2.2e-16
```

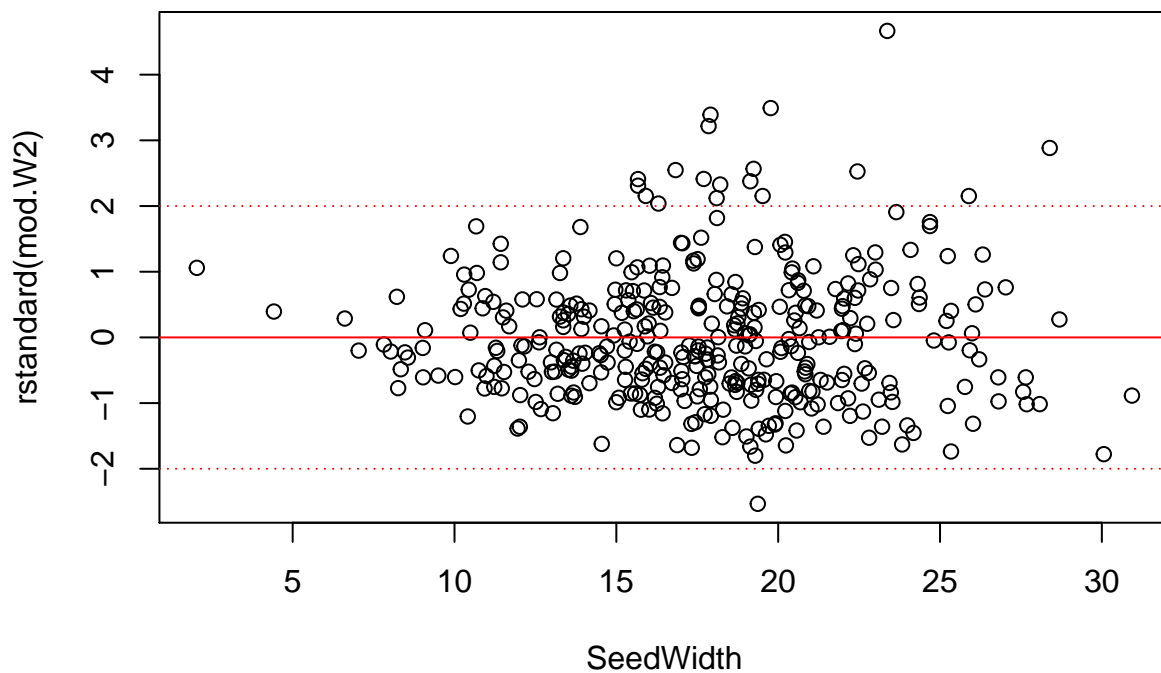
```
anova(mod.W, mod.W2)
```

```
## Analysis of Variance Table
##
## Model 1: DT.Avg ~ sqrt(SeedWidth)
```

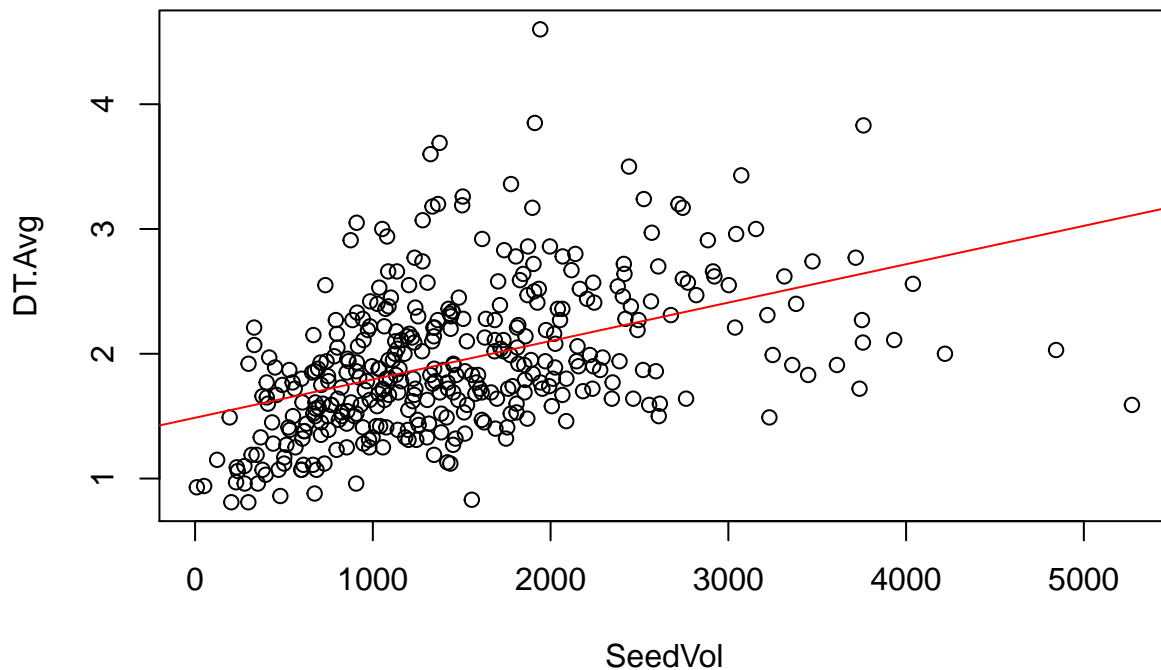


```
## Model 2: DT.Avg ~ SeedWidth + I(SeedWidth^2)
##   Res.Df    RSS Df Sum of Sq    F Pr(>F)
## 1    371 92.738
## 2    370 91.960  1   0.77791 3.1299 0.07769 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
plot(rstandard(mod.W2) ~ SeedWidth, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```



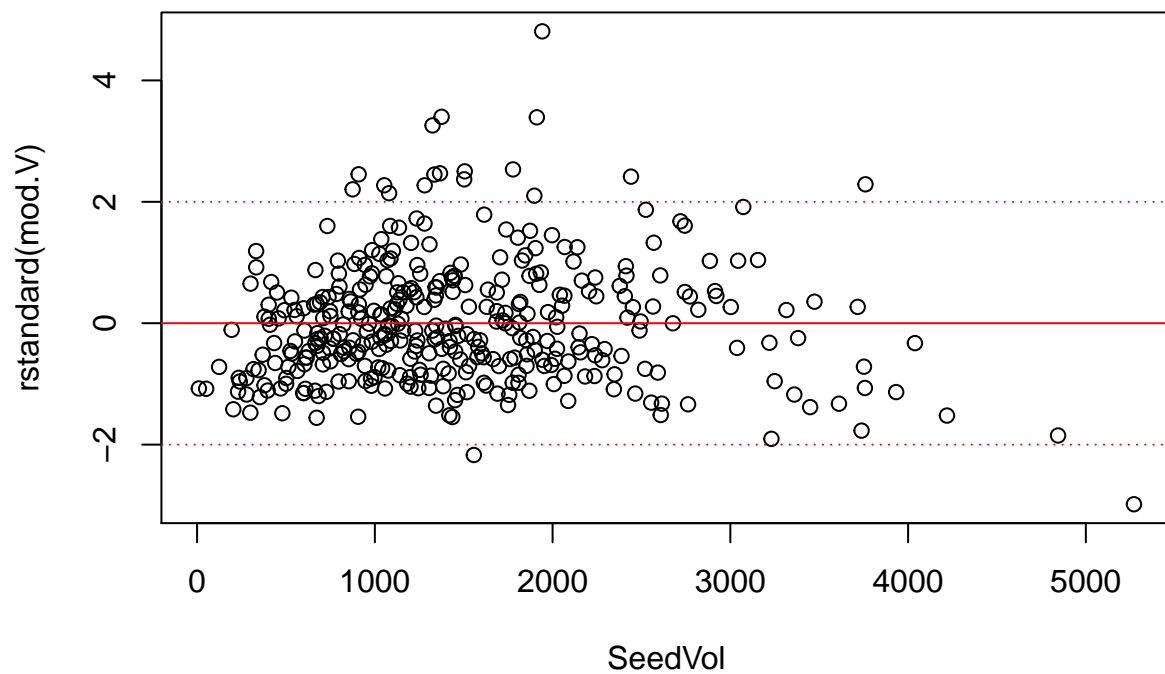
```
# Average DT ~ pappus conical volume
mod.V <- lm(DT.Avg ~ SeedVol, data = data.new)
plot(DT.Avg ~ SeedVol, data = data.new)
abline(mod.V, col = "red")
```



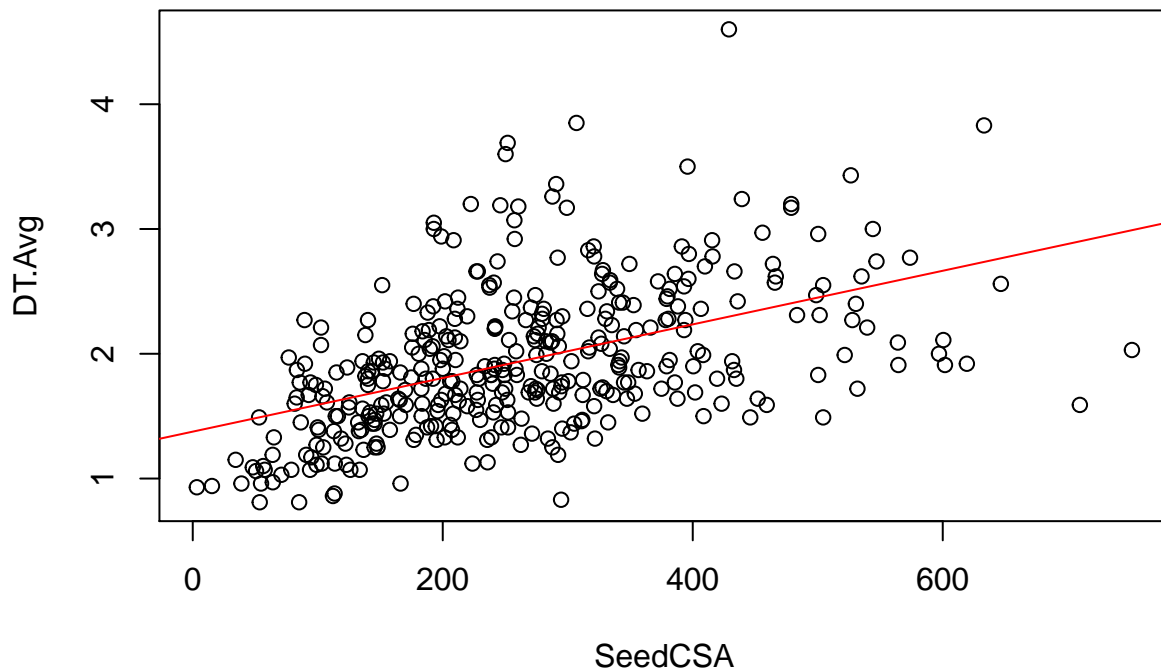
```
summary(mod.V)
```

```
##
## Call:
## lm(formula = DT.Avg ~ SeedVol, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.51863 -0.37137 -0.06468  0.27644  2.51545
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.487e+00  5.439e-02  27.343  <2e-16 ***
## SeedVol      3.076e-04  3.185e-05   9.658  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.524 on 371 degrees of freedom
## Multiple R-squared:  0.2009, Adjusted R-squared:  0.1988
## F-statistic: 93.28 on 1 and 371 DF, p-value: < 2.2e-16

plot(rstandard(mod.V) ~ SeedVol, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```



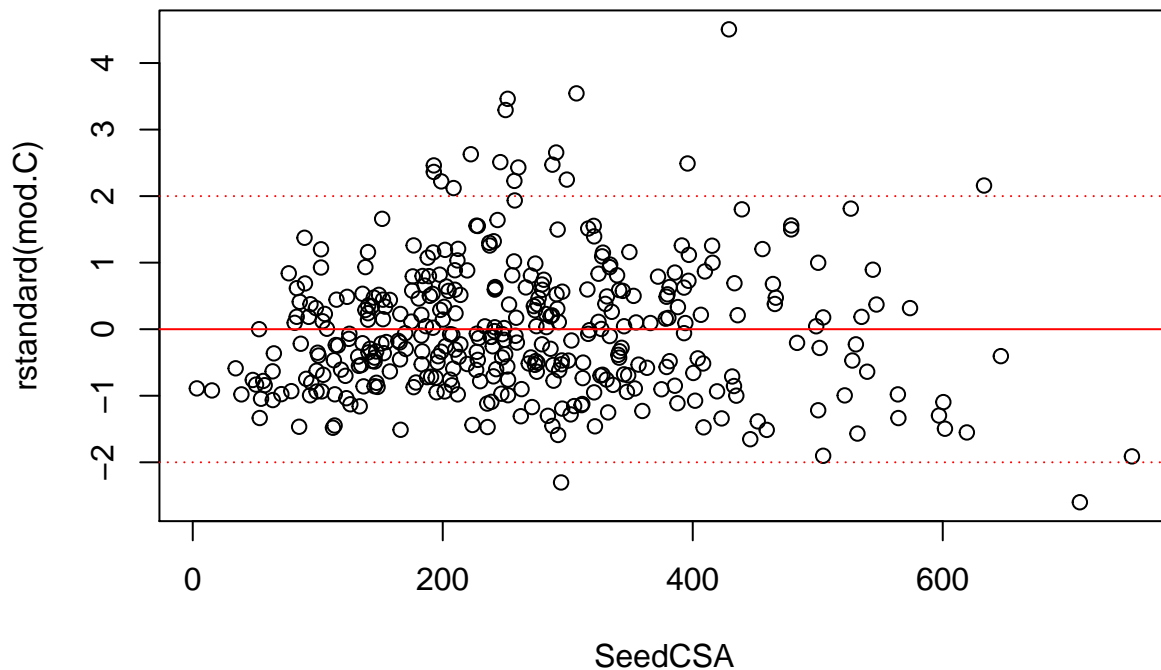
```
# Average DT ~ pappus max circular CSA
mod.C <- lm(DT.Avg ~ SeedCSA, data = data.new)
plot(DT.Avg ~ SeedCSA, data = data.new)
abline(mod.C, col = "red")
```



```
summary(mod.C)
```

```
##
## Call:
## lm(formula = DT.Avg ~ SeedCSA, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.31084 -0.36313 -0.05802  0.29448  2.30240
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.3759000  0.0593291   23.19  <2e-16 ***
## SeedCSA      0.0021487  0.0002012   10.68  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5127 on 371 degrees of freedom
## Multiple R-squared:  0.2351, Adjusted R-squared:  0.233
## F-statistic: 114 on 1 and 371 DF, p-value: < 2.2e-16

plot(rstandard(mod.C) ~ SeedCSA, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```



```
# Average DT ~ pappus width and length
summary(lm(DT.Avg ~ SeedLength + SeedWidth, data = data))

##
## Call:
## lm(formula = DT.Avg ~ SeedLength + SeedWidth, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.22288 -0.34793 -0.07354  0.27495  2.27674
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.863936   0.168424   5.130 4.7e-07 ***
## SeedLength  -0.004483   0.009994  -0.449   0.654
## SeedWidth    0.065049   0.005817  11.182 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.503 on 370 degrees of freedom
## (20 observations deleted due to missingness)
## Multiple R-squared:  0.2656, Adjusted R-squared:  0.2617
## F-statistic: 66.92 on 2 and 370 DF, p-value: < 2.2e-16
summary(lm(DT.Avg ~ SeedWidth + SeedLength, data = data))
```

```
##
```

```
## Call:
## lm(formula = DT.Avg ~ SeedWidth + SeedLength, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.22288 -0.34793 -0.07354  0.27495  2.27674
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  0.863936   0.168424   5.130  4.7e-07 ***
## SeedWidth    0.065049   0.005817  11.182 < 2e-16 ***
## SeedLength  -0.004483   0.009994  -0.449   0.654
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.503 on 370 degrees of freedom
## (20 observations deleted due to missingness)
## Multiple R-squared:  0.2656, Adjusted R-squared:  0.2617
## F-statistic: 66.92 on 2 and 370 DF, p-value: < 2.2e-16
summary(lm(DT.Avg ~ SeedWidth + SeedLength + SeedWidth:SeedLength, data = data))

##
## Call:
## lm(formula = DT.Avg ~ SeedWidth + SeedLength + SeedWidth:SeedLength,
##     data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.22876 -0.35217 -0.06607  0.27079  2.25172
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.547959   0.484377   1.131  0.25868
## SeedWidth      0.083834   0.027616   3.036  0.00257 **
## SeedLength     0.014981   0.029707   0.504  0.61437
## SeedWidth:SeedLength -0.001142   0.001641  -0.696  0.48698
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5034 on 369 degrees of freedom
## (20 observations deleted due to missingness)
## Multiple R-squared:  0.2666, Adjusted R-squared:  0.2606
## F-statistic: 44.71 on 3 and 369 DF, p-value: < 2.2e-16
# Average DT ~ warming and mowing treatments
mod.WM <- lm(DT.Avg ~ Mow + Warming + Mow:Warming, data = data)
summary(mod.WM)
```

```
##
## Call:
## lm(formula = DT.Avg ~ Mow + Warming + Mow:Warming, data = data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
```

```
## -1.27566 -0.39450 -0.02566 0.35140 2.38434
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   1.91413    0.06964  27.485 < 2e-16 ***
## MowE          0.30153    0.08793   3.429 0.000673 ***
## MowL          0.34462    0.20747   1.661 0.097527 .
## WarmingW      -0.18875    0.09701  -1.946 0.052424 .
## MowE:WarmingW -0.18328    0.12246  -1.497 0.135328
## MowL:WarmingW -0.52846    0.24363  -2.169 0.030699 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5528 on 377 degrees of freedom
## (10 observations deleted due to missingness)
## Multiple R-squared:  0.1292, Adjusted R-squared:  0.1177
## F-statistic: 11.19 on 5 and 377 DF, p-value: 4.525e-10
```

```
anova(mod.WM)
```

```
## Analysis of Variance Table
##
## Response: DT.Avg
##             Df Sum Sq Mean Sq F value    Pr(>F)
## Mow           2   5.221   2.6106   8.5441 0.000235 ***
## Warming        1  10.212  10.2122  33.4229 1.557e-08 ***
## Mow:Warming    2   1.662   0.8308   2.7190 0.067233 .
## Residuals    377 115.191   0.3055
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# Average DT ~ warming and early mowing treatment
data.new.2 <- subset(data.new, Mow != "L")
mod.WM2 <- lm(DT.Avg ~ Mow + Warming, data = data.new.2)
summary(mod.WM2)
```

```
##
## Call:
## lm(formula = DT.Avg ~ Mow + Warming, data = data.new.2)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.24043 -0.37667 -0.04667  0.33333  2.41957
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)   1.97340    0.05821  33.902 < 2e-16 ***
## MowE          0.20703    0.06219   3.329 0.000965 ***
## WarmingW      -0.30376    0.06016  -5.049 7.2e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5617 on 346 degrees of freedom
## Multiple R-squared:  0.09556, Adjusted R-squared:  0.09033
## F-statistic: 18.28 on 2 and 346 DF, p-value: 2.843e-08
```

```
anova(mod.WM2)
```

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

```
##
```

```
## Response: DT.Avg
```

##	Df	Sum Sq	Mean Sq	F value	Pr(>F)
## Mow	1	3.490	3.4905	11.064	0.0009747 ***
## Warming	1	8.043	8.0425	25.493	7.196e-07 ***
## Residuals	346	109.157	0.3155		

```
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```