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 reponses 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.

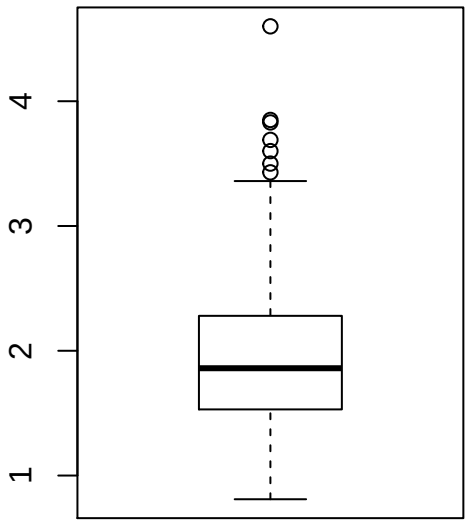
Questions:

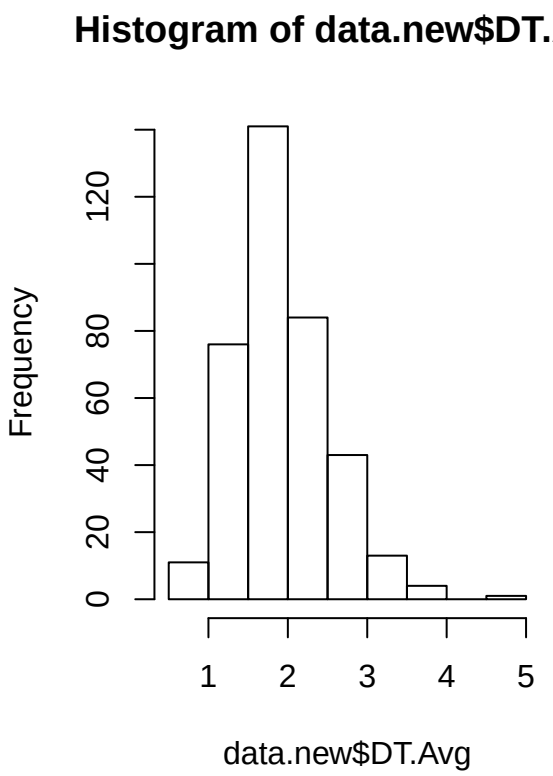
1. Strategy for handling late mow

To Dos:

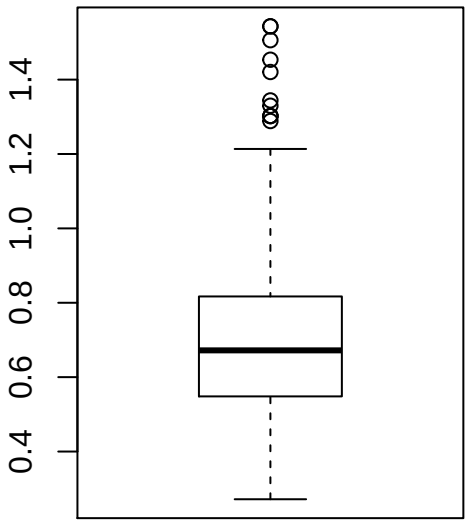
1. GLM

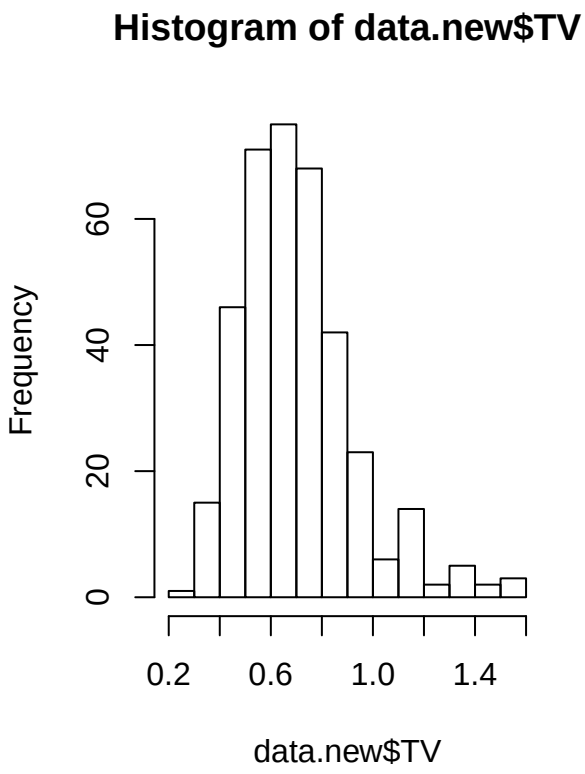
```
# Distribution of average DT
par(mfrow = c(1,2))
boxplot(data.new$DT.Avg)
hist(data.new$DT.Avg)
```






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



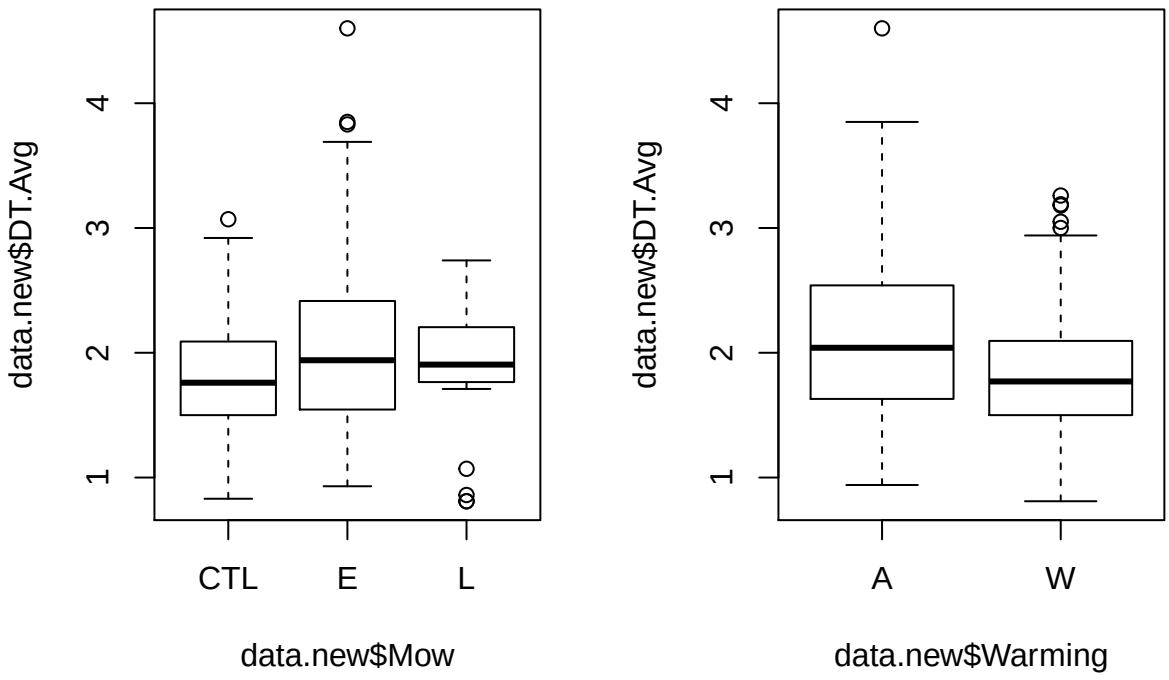


Does drop time/terminal velocity vary by treatment?

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
```

```r
# 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
```

```r
# 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
```

```r
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

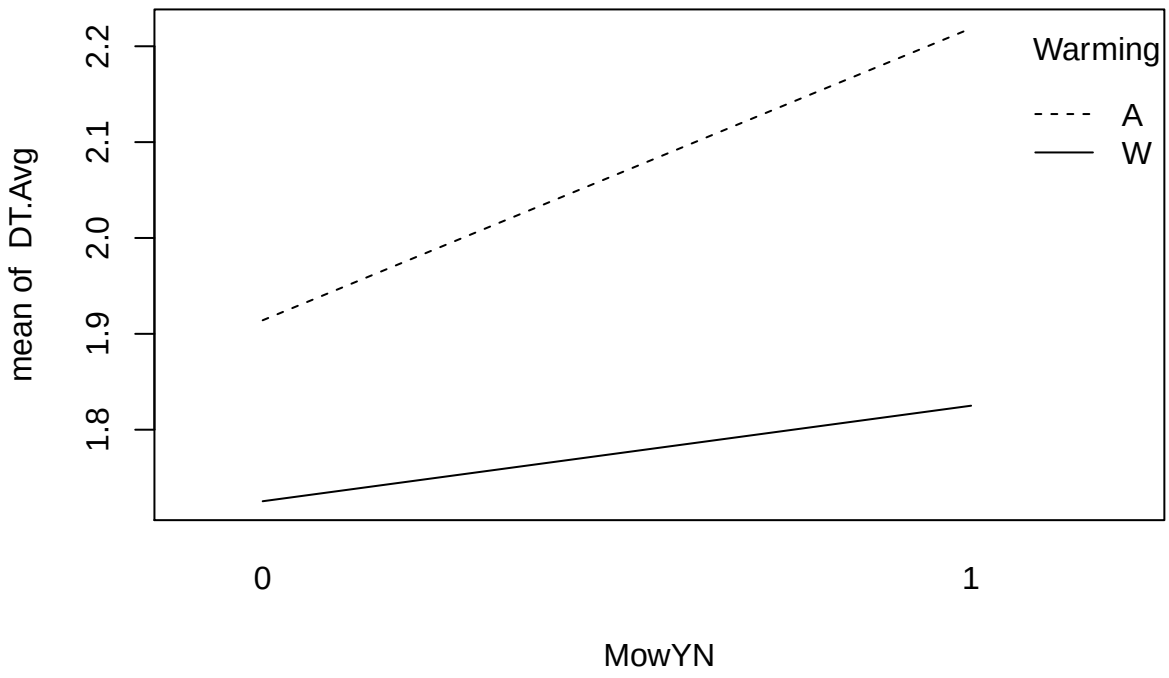
```
# interaction
mod.int = lm(DT.Avg ~ MowYN + Warming + MowYN:Warming, data= data.new)
summary(mod.int)
```

```
##
## 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))
```



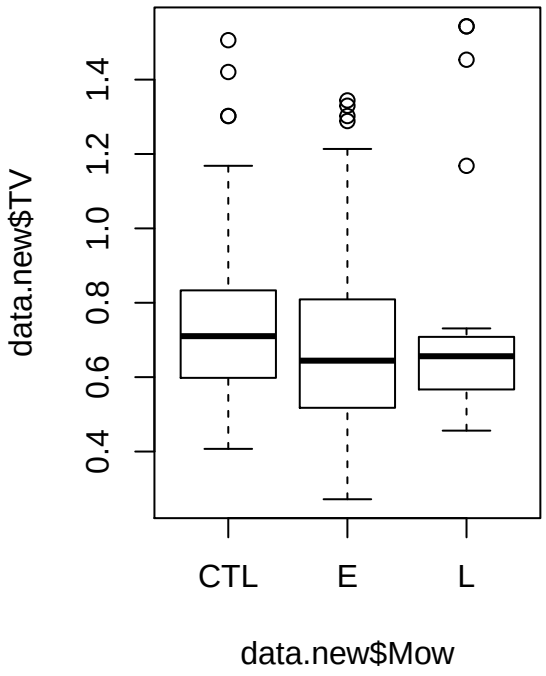
Conclusions:

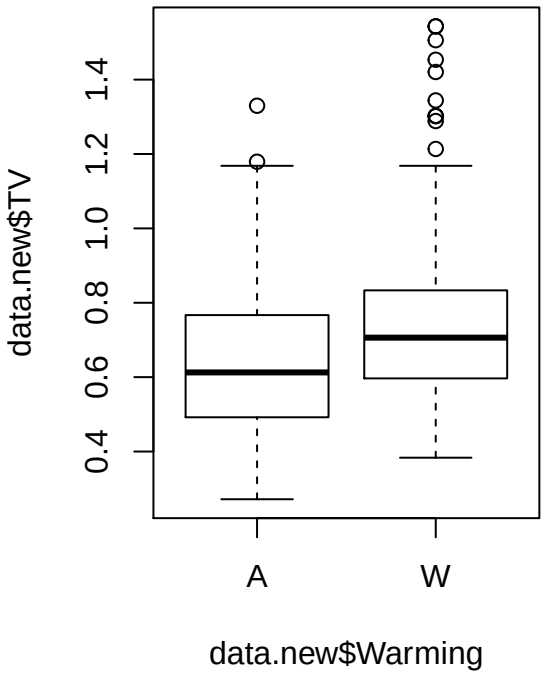
1. Mowing (regardless of timing) significantly increases drop time. This difference appears to be driven by the early mow treatment, but it's not clear whether late mow shows no effect because there is truly no effect or becasue there are too few data. **Question: Group all mowing together into mowing 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)
```





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
```

```r
# 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
```

```r
# 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
```

```r
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

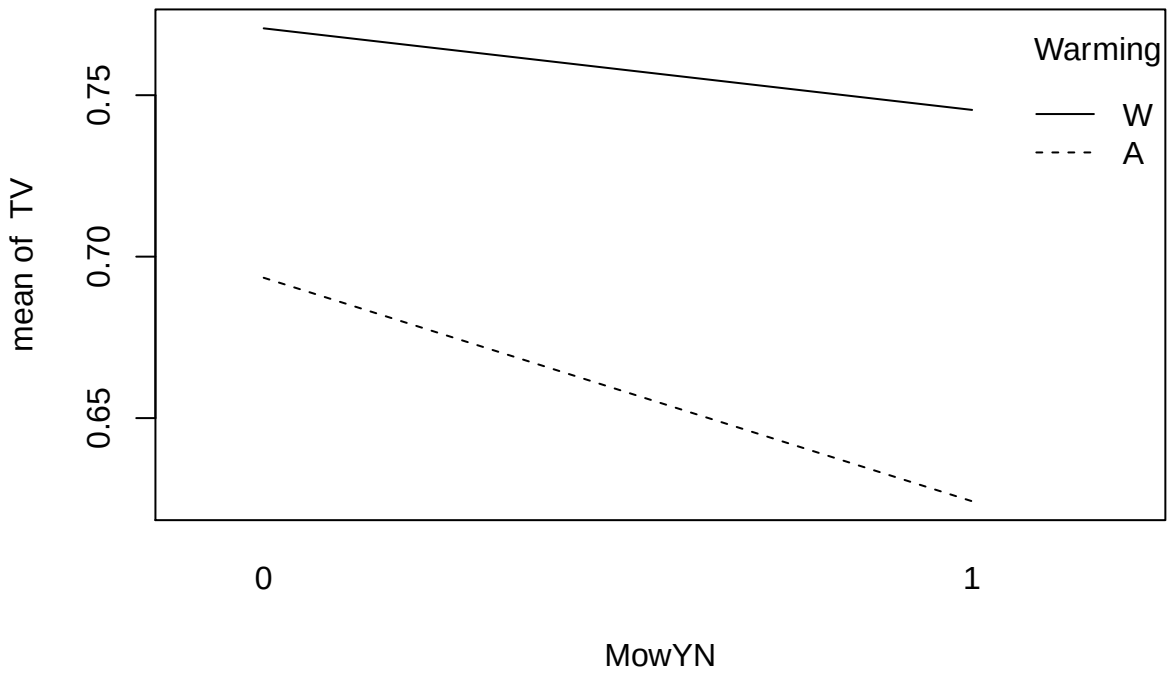
```
# interaction (mow YN)
mod.intYN = lm(TV ~ MowYN + Warming + MowYN:Warming, data= data.new)
summary(mod.intYN)
```

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

```
## Analysis of Variance Table
##
## Model 1: TV ~ Warming
## Model 2: TV ~ MowYN + Warming + MowYN:Warming
## Model 3: TV ~ MowYN + Warming
##   Res.Df    RSS Df Sum of Sq      F  Pr(>F)
## 1    371 17.149
## 2    369 16.927  2  0.222484 2.4251 0.08988 .
## 3    370 16.968 -1 -0.040821 0.8899 0.34612
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

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

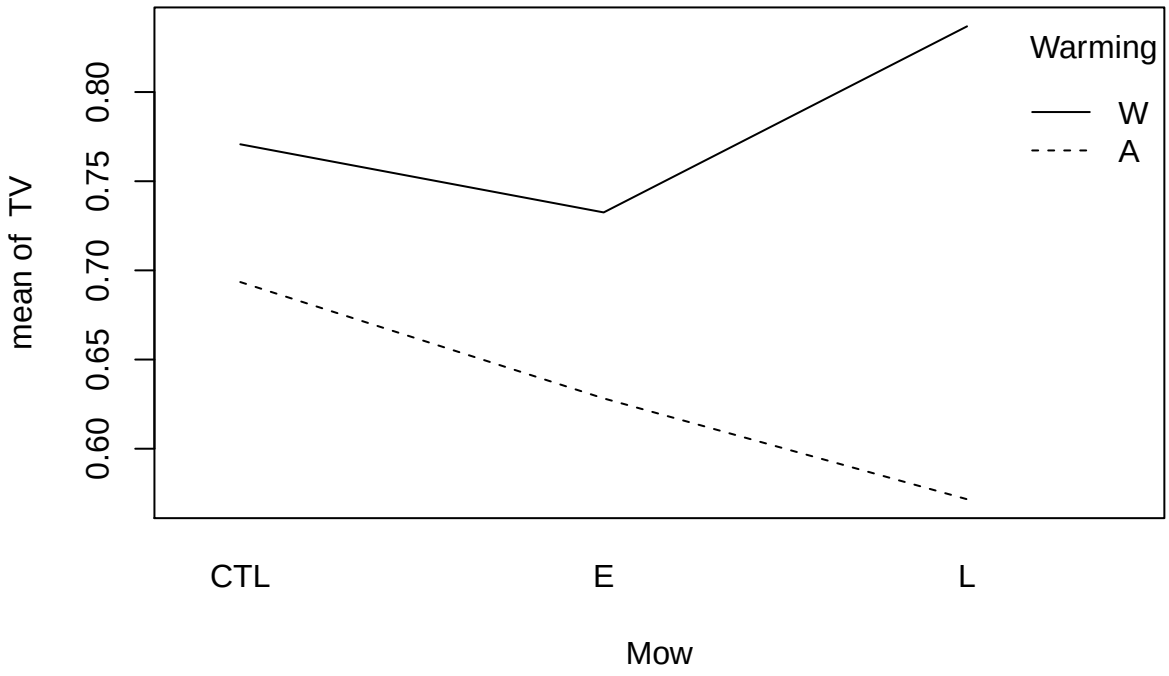
```
##
## Call:
## lm(formula = TV ~ Mow + Warming + Mow:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.35648 -0.15111 -0.03901  0.09852  0.73533
##
## Coefficients:
```

```
##                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.int, lm(TV~Mow + Warming, data = data.new))
```

```
## Analysis of Variance Table
##
## Model 1: TV ~ Warming
## Model 2: TV ~ Mow + Warming + Mow:Warming
## Model 3: TV ~ Mow + Warming
##   Res.Df    RSS Df Sum of Sq      F Pr(>F)
## 1    371 17.149
## 2    367 16.750  4   0.39884 2.1846 0.0702 .
## 3    369 16.912 -2  -0.16178 1.7723 0.1714
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Conclusions:

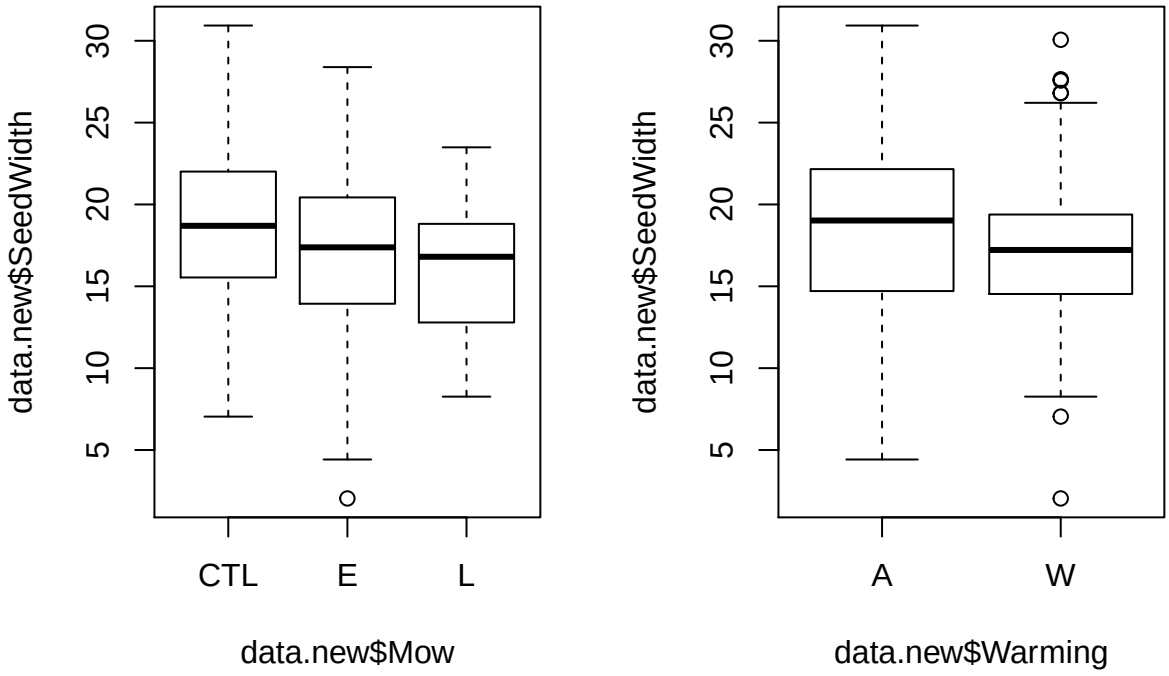
1. Mowing has weak or no effect on terminal velocity.
2. Warming significantly increases terminal velocity. There may be a weak interaction between late mowing and warmed plants which further increases terminal velocity, though partial F-test does not suggest these terms add more information.

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
```

```r
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

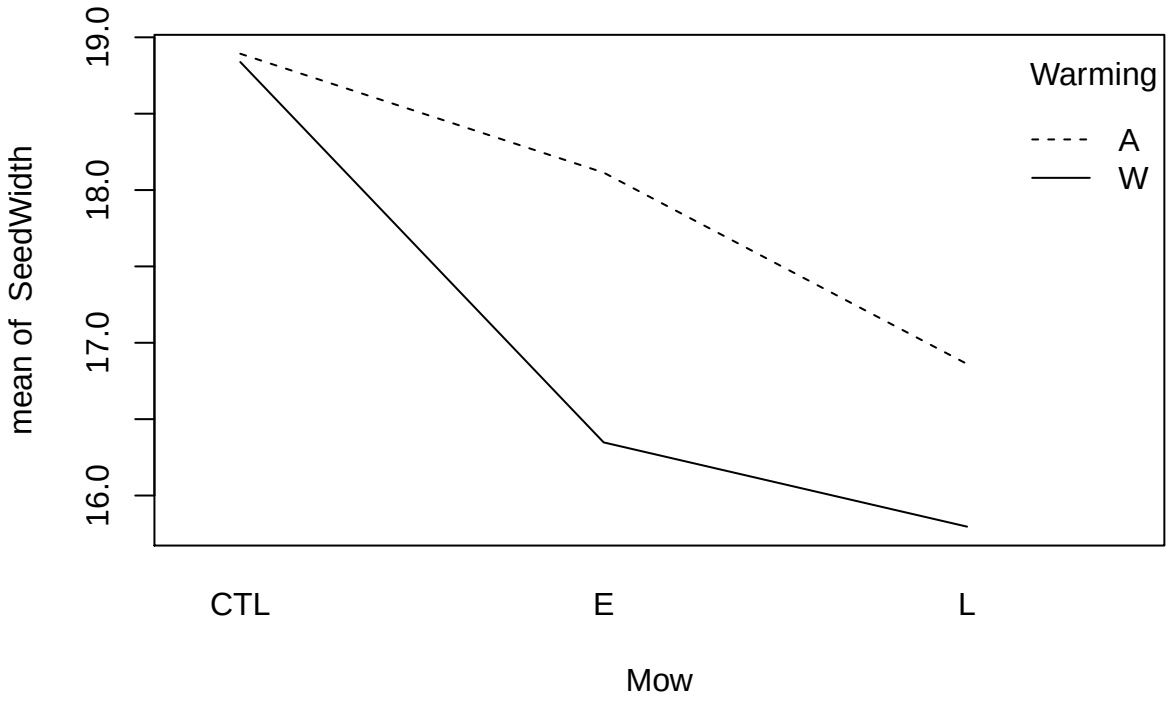
```r
# interaction (including E/L mow differentiation)
mod.int = lm(SeedWidth ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)
```

```
##
## 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
```

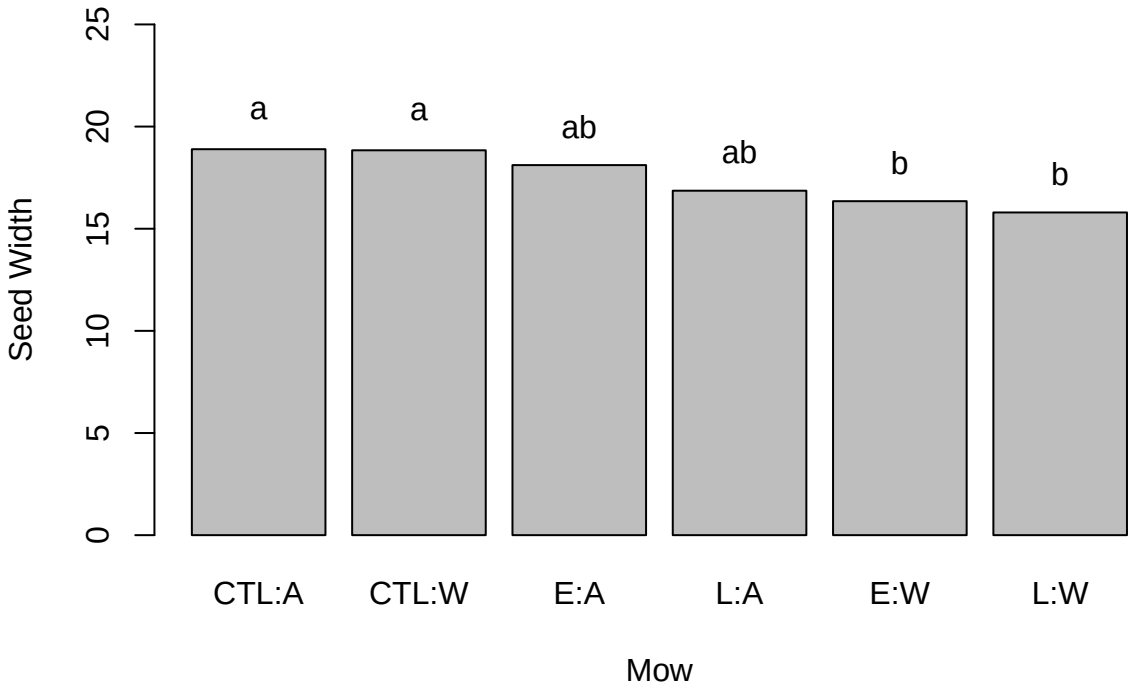
```r
anova(mod.int)
```

```
## 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)
```

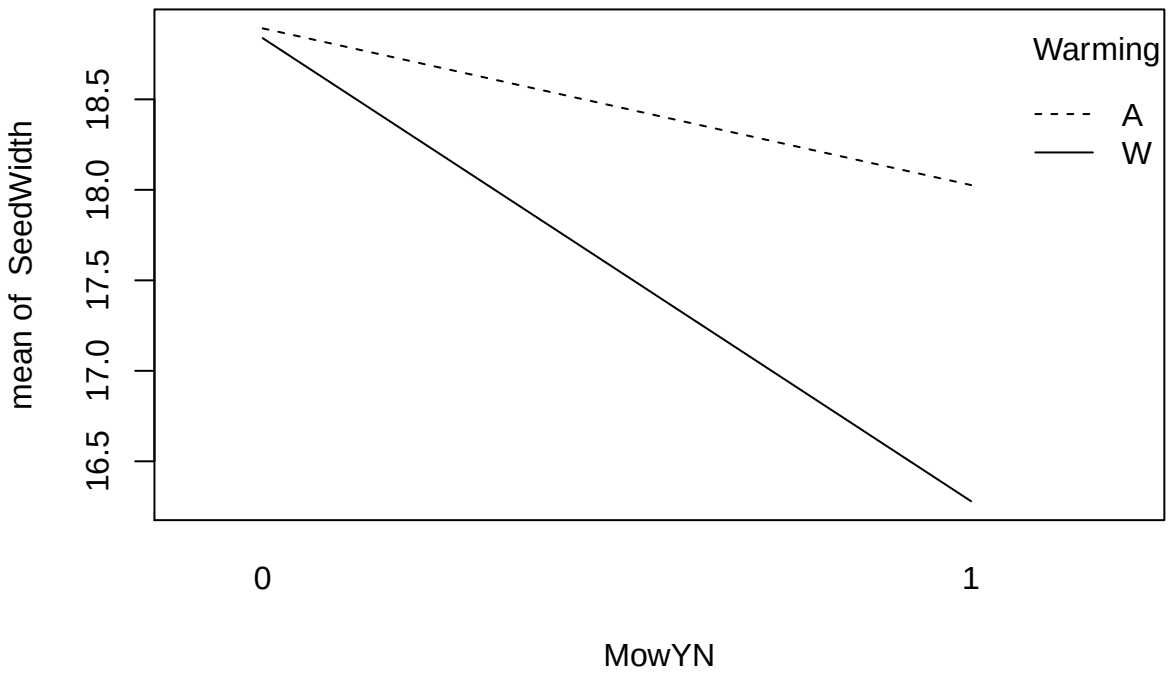
```
##
## Call:
## lm(formula = SeedWidth ~ MowYN + Warming + MowYN:Warming, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -14.2393  -3.0324   0.1276   3.0638  12.0376
##
```

```
## 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
```

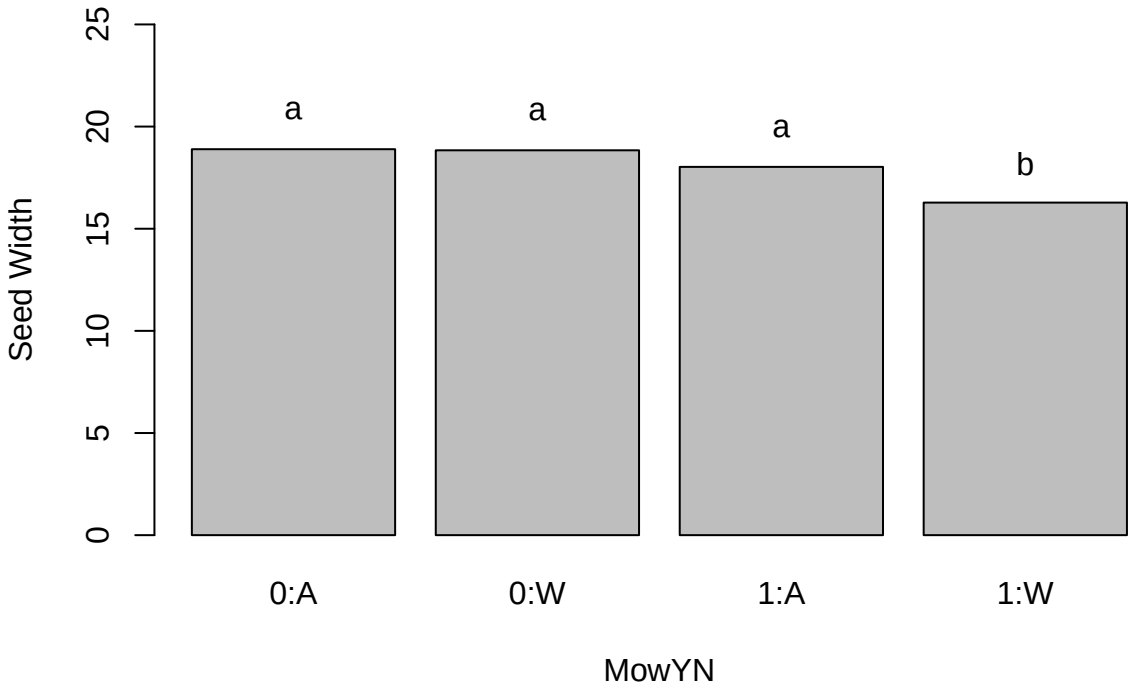
```
anova(mod.intYN)
```

```
## 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
```

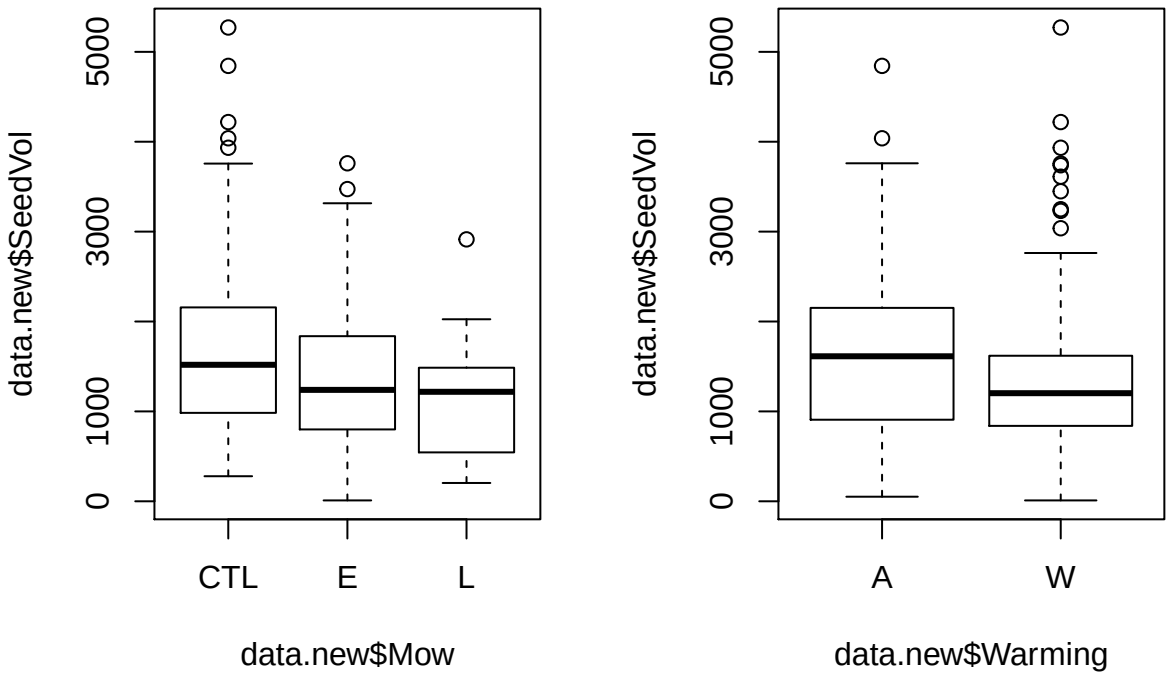
Conclusions:

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

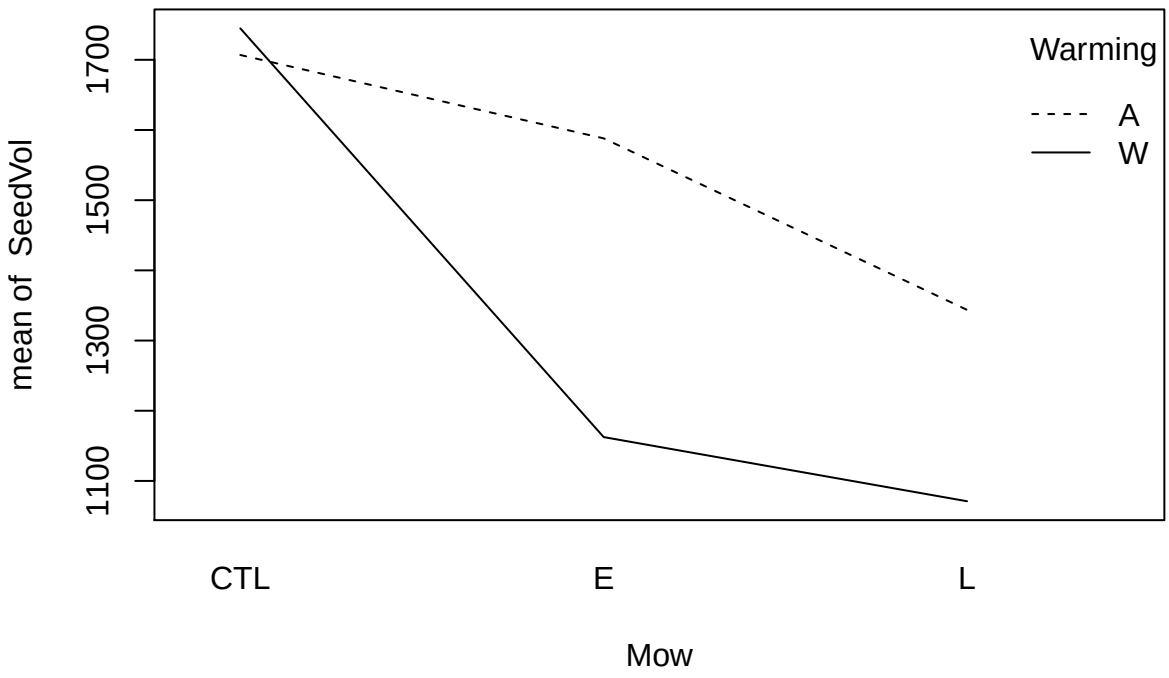
```
# interaction (including E/L mow differentiation)
mod.int = lm(SeedVol ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)
```

```
##
## 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
```

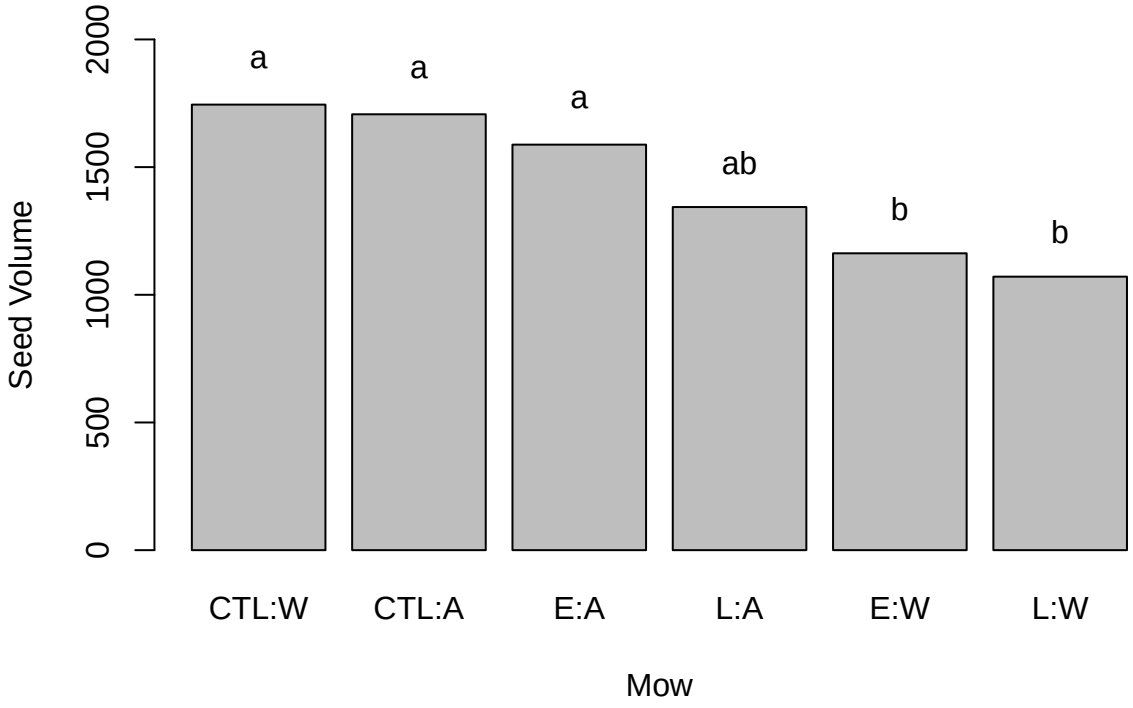
```
anova(mod.int)
```

```
## 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)
```

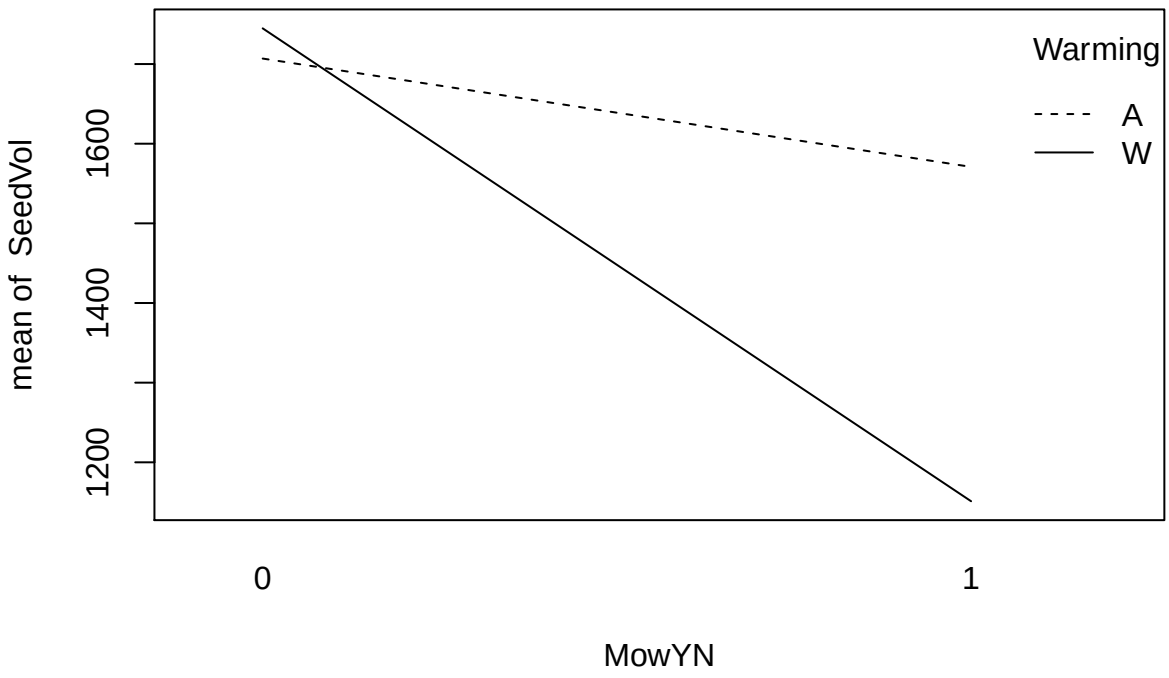
```
##
## Call:
## lm(formula = SeedVol ~ MowYN + Warming + MowYN:Warming, data = data.new)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1519.8  -598.5   -91.8   403.3  3525.8
##
```

```
## 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
```

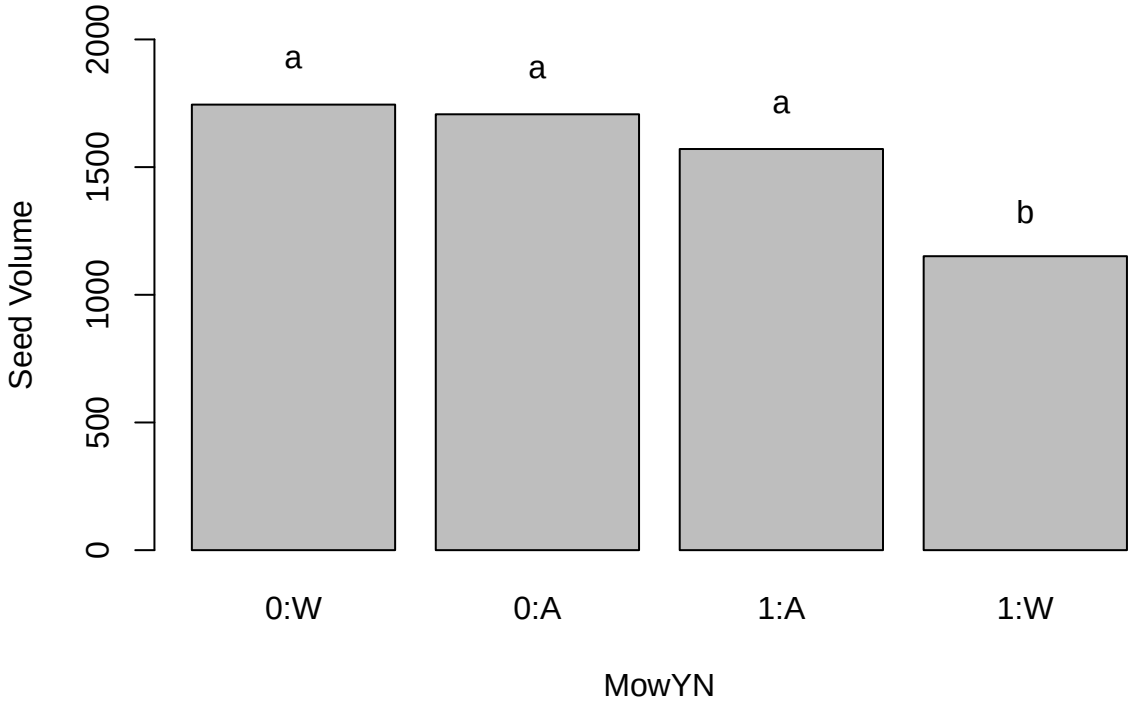
```
anova(mod.intYN)
```

```
## 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
```

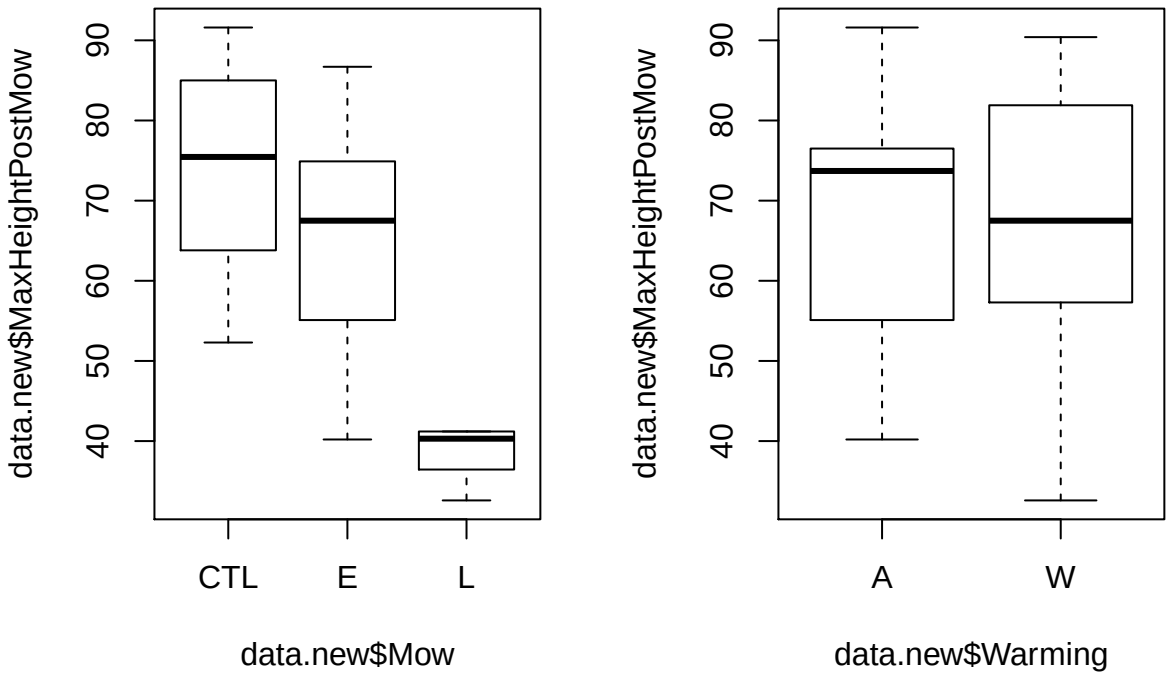
Conclusions:

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

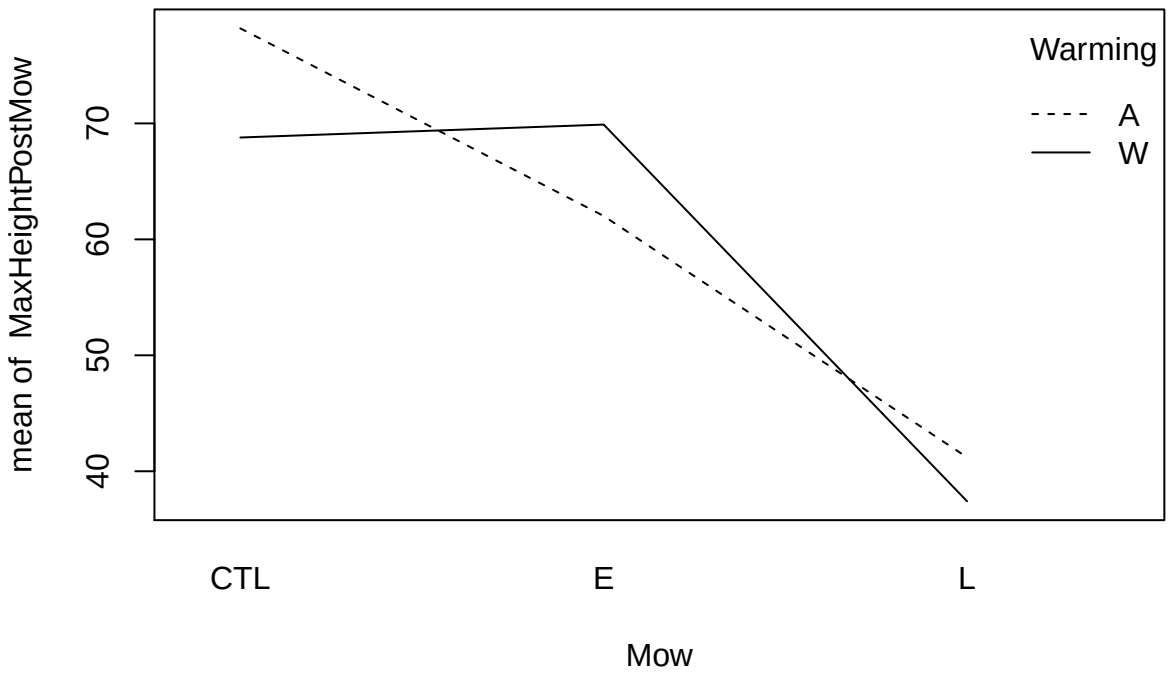
```
# interaction (including E/L mow differentiation)
mod.int = lm(MaxHeightPostMow ~ Mow + Warming + Mow:Warming, data= data.new)
summary(mod.int)
```

```
##
## 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
```

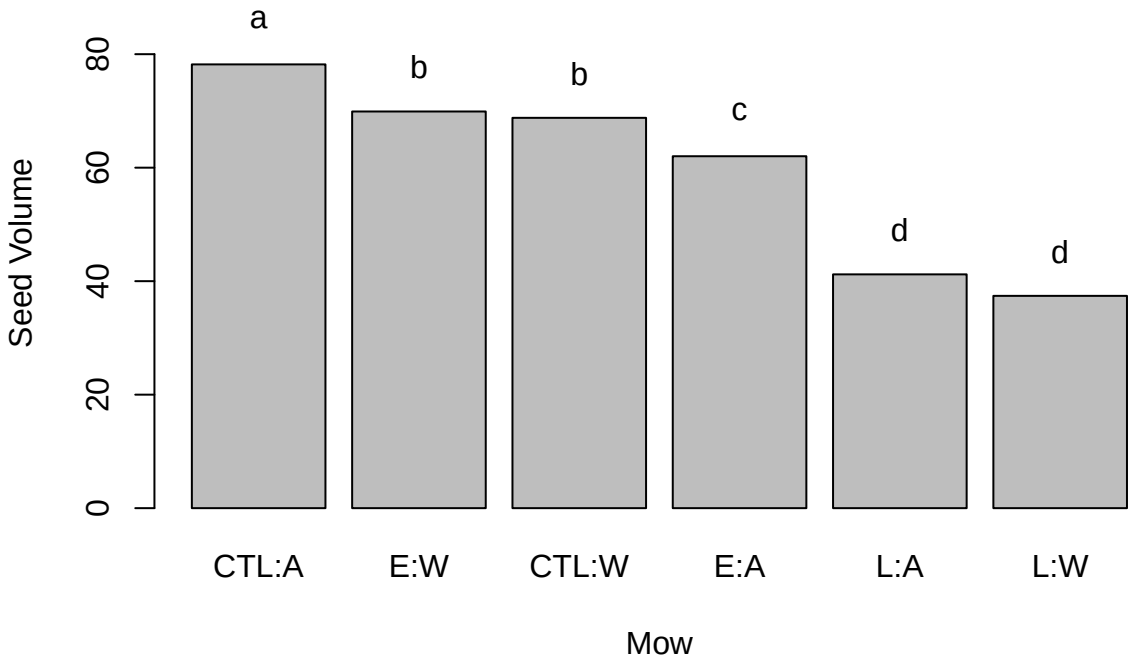
```
anova(mod.int)
```

```
## 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)
```

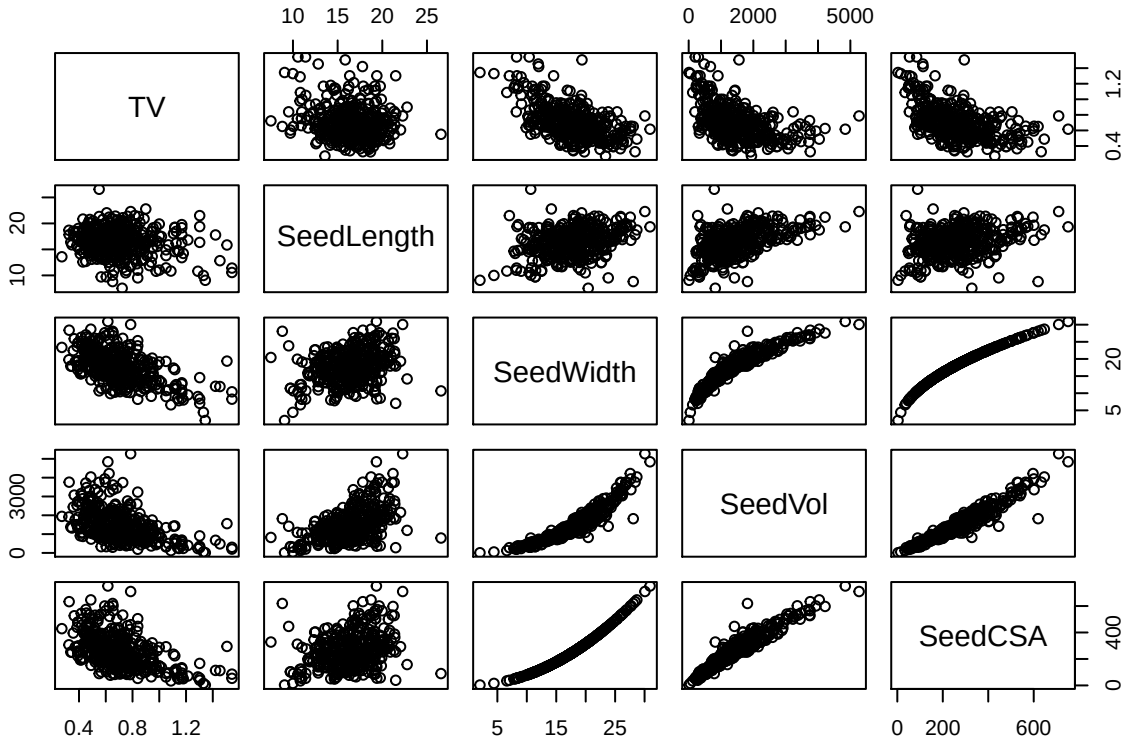
```
## Analysis of Variance Table
##
## Model 1: MaxHeightPostMow ~ Mow
## Model 2: MaxHeightPostMow ~ Mow + Warming
## Model 3: MaxHeightPostMow ~ Mow + Warming + Mow:Warming
##   Res.Df   RSS Df Sum of Sq       F   Pr(>F)
## 1    370 56755
## 2    369 56635  1     119.6  0.8705   0.3514
## 3    367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

Conclusions:

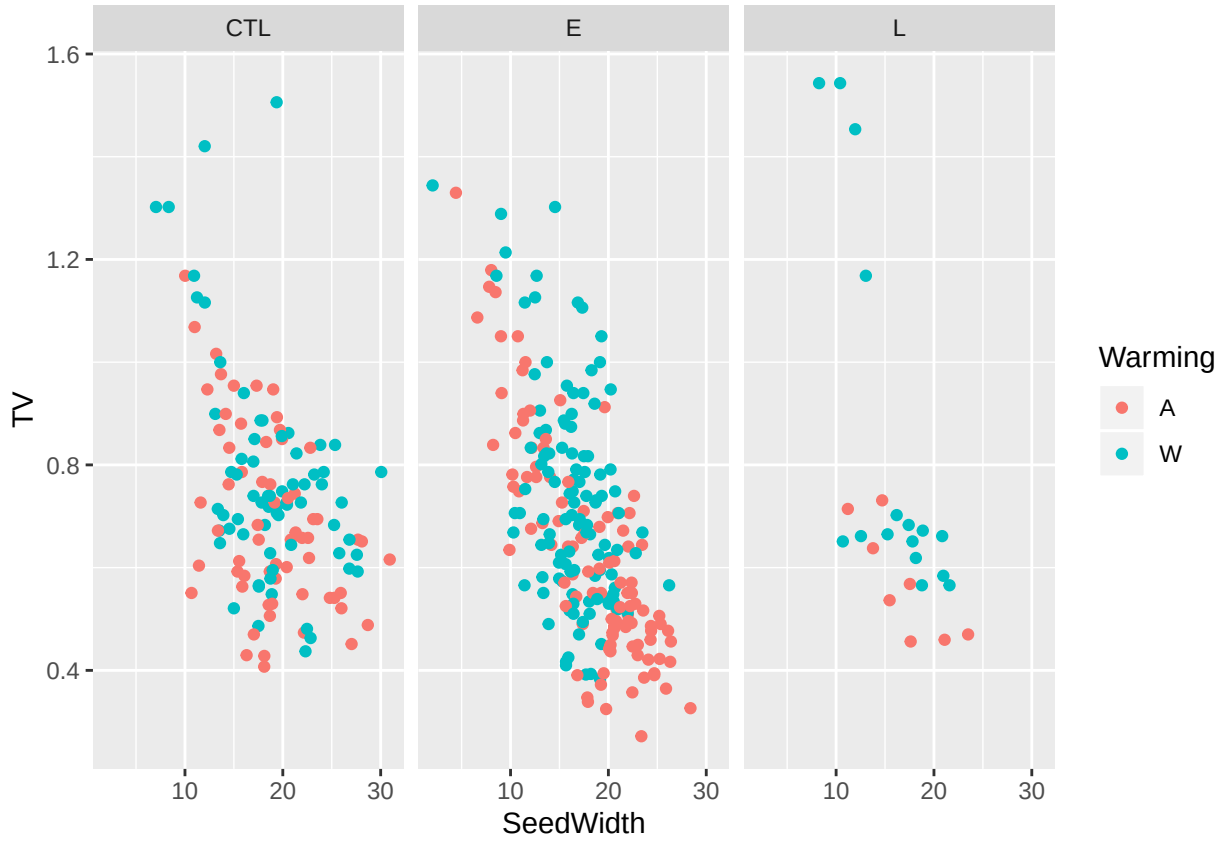
1. Mowing significantly reduces plant height. Warming allows early mowed plants to reach similar heights as the warmed control plants. There is no significant difference between late mowed plants by warming. Non-mowed ambient plants are taller than non-mowed warmed plants.

Is Terminal Velocity predicted by seed shape parameters?

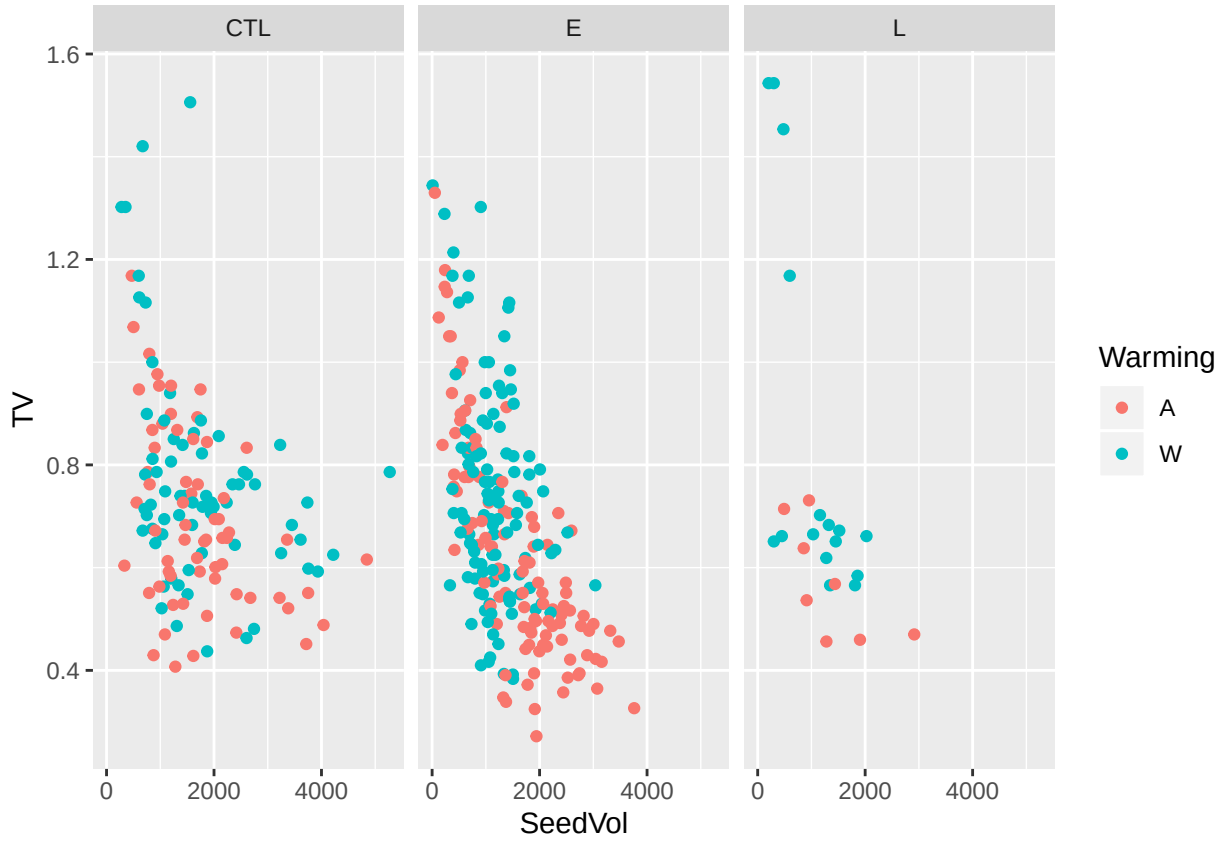
```
# Potential Predictors
pairs(data.new[,c("TV","SeedLength","SeedWidth", "SeedVol","SeedCSA")])
```



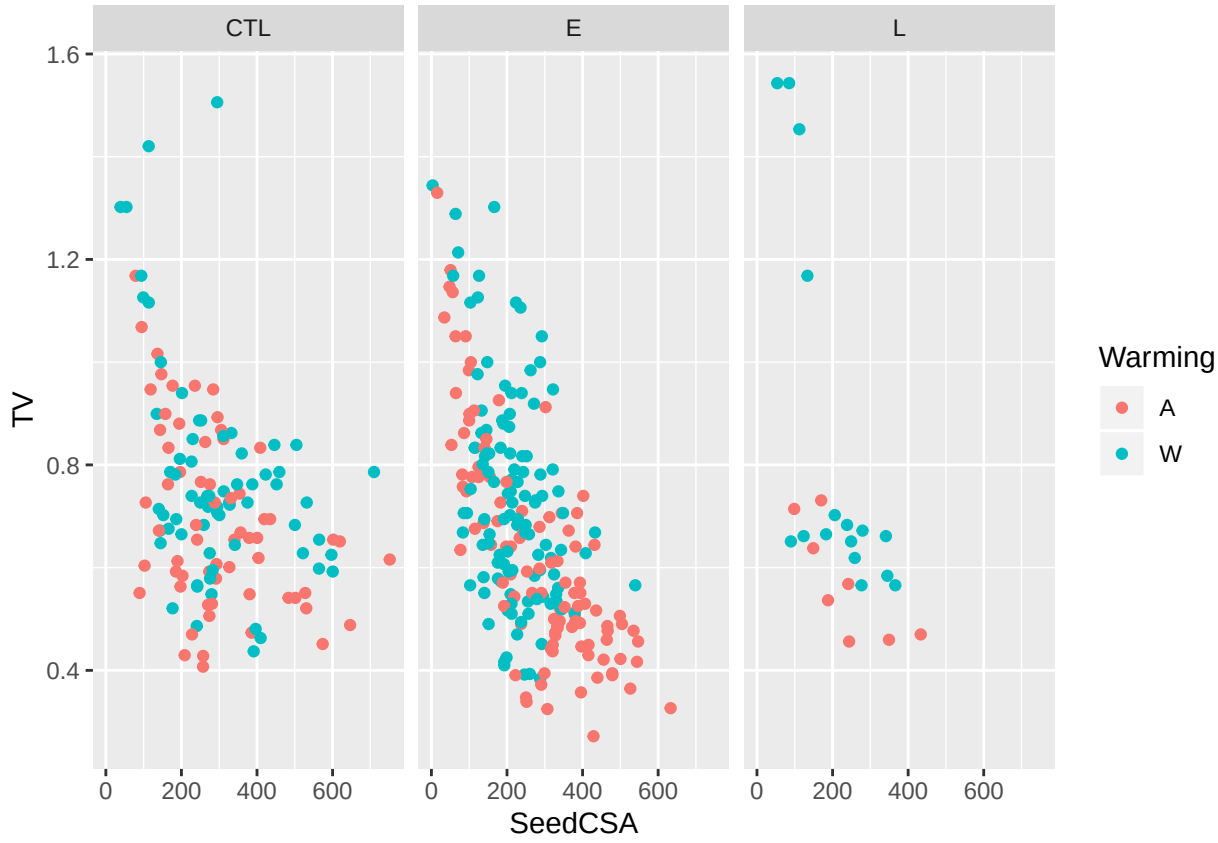

```
# plot TV vs. seed width by treatment
ggplot(data = data.new, aes(x = SeedWidth, y = TV, color = Warming))+
  geom_point()+
  facet_wrap(data.new$Mow)
```




```
# 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)
```

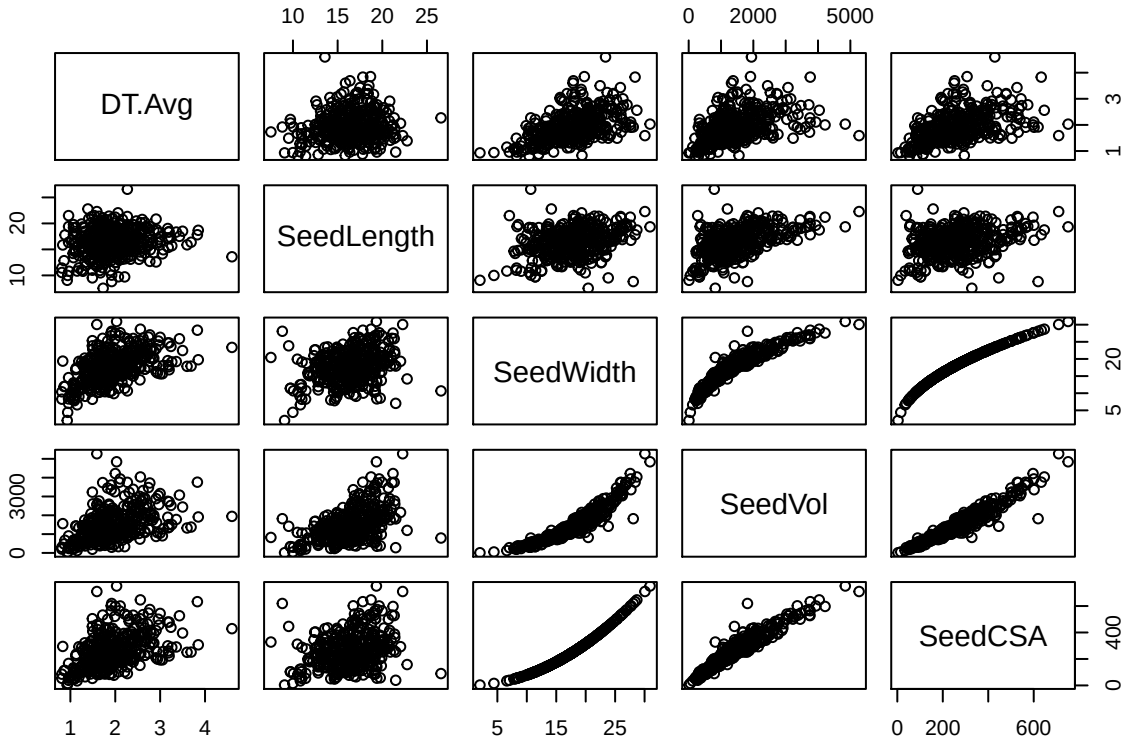



```
# plot TV vs. seed CSA by treatment
ggplot(data = data.new, aes(x = SeedCSA, y = TV, color = Warming))+
  geom_point()+
  facet_wrap(data.new$Mow)
```

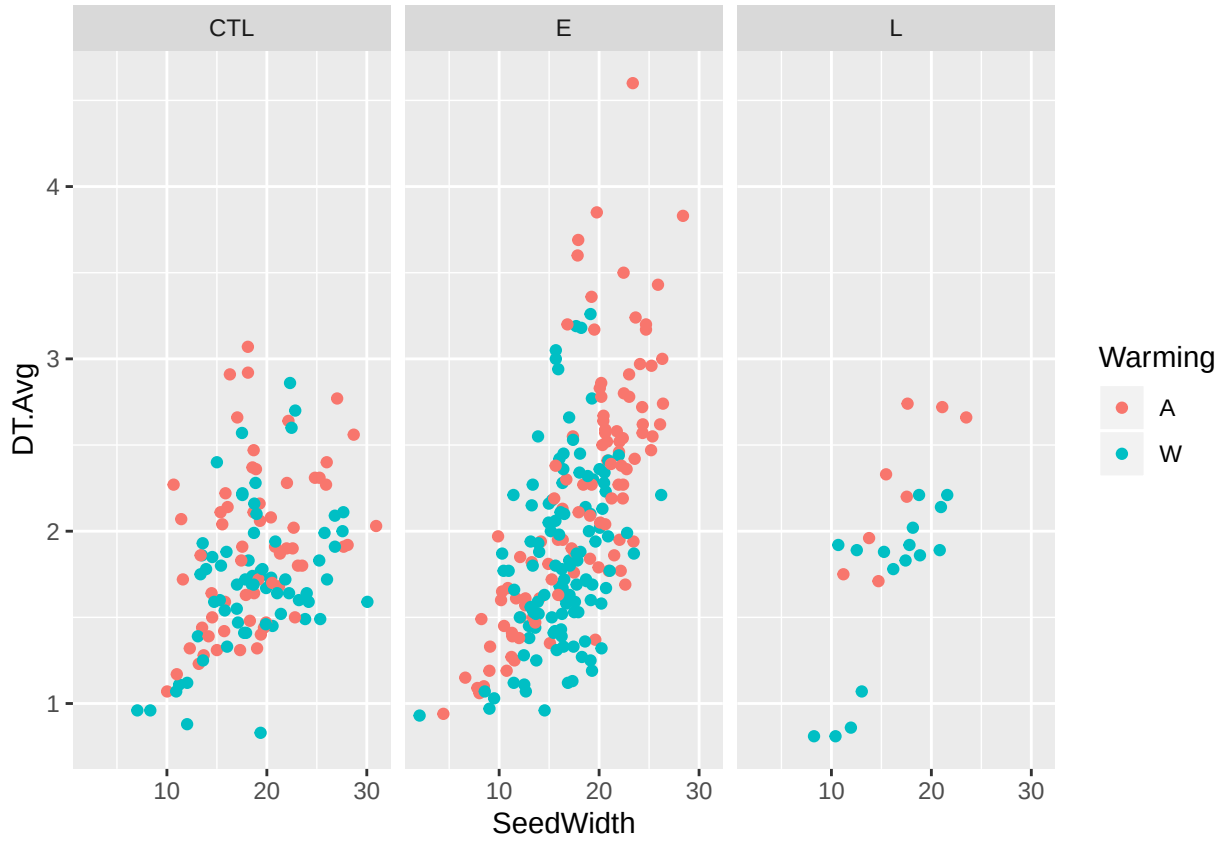


Is drop time predicted by seed shape parameters?

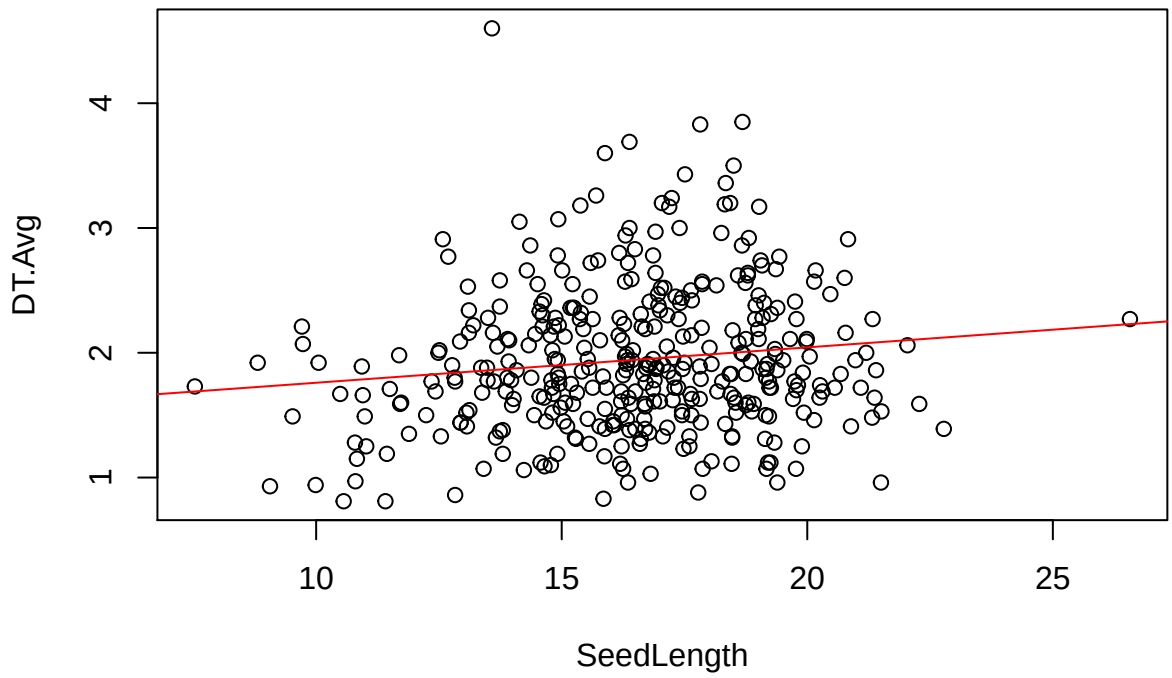
```
# Potential Predictors
pairs(data.new[,c("DT.Avg","SeedLength","SeedWidth", "SeedVol","SeedCSA")])
```




```
# 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)
```



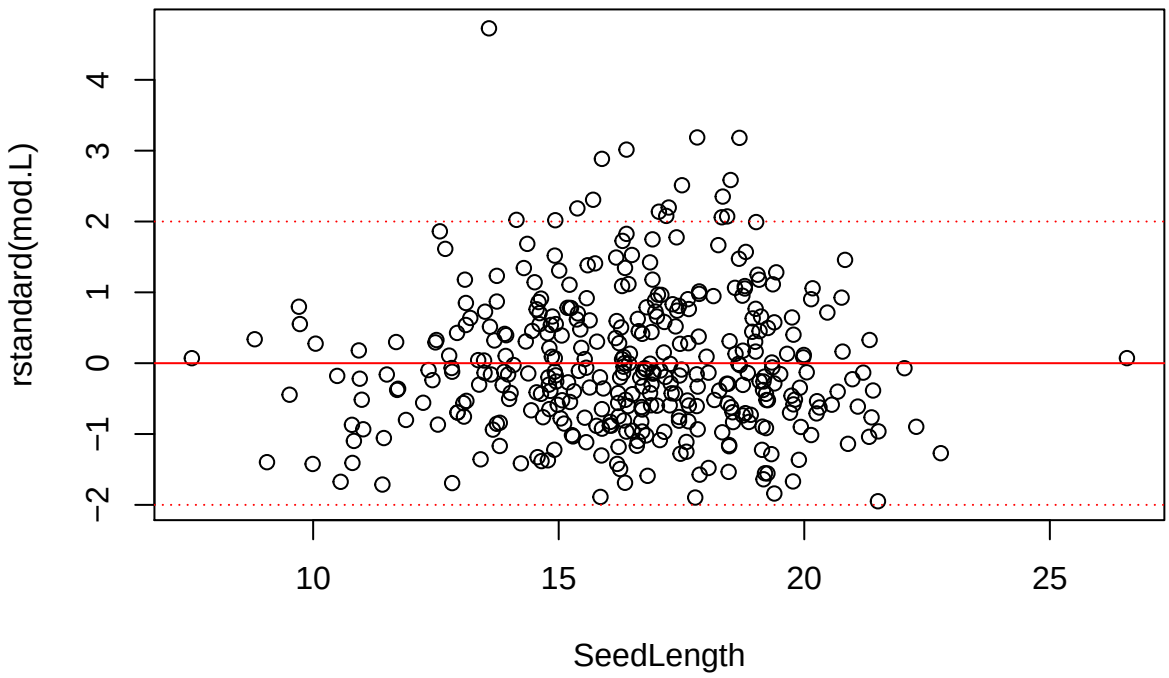

```
# Average DT ~ pappus length
mod.L <- lm(DT.Avg ~ SeedLength, data = data.new)
plot(DT.Avg ~ SeedLength, data = data.new)
abline(mod.L, col = "red")
```



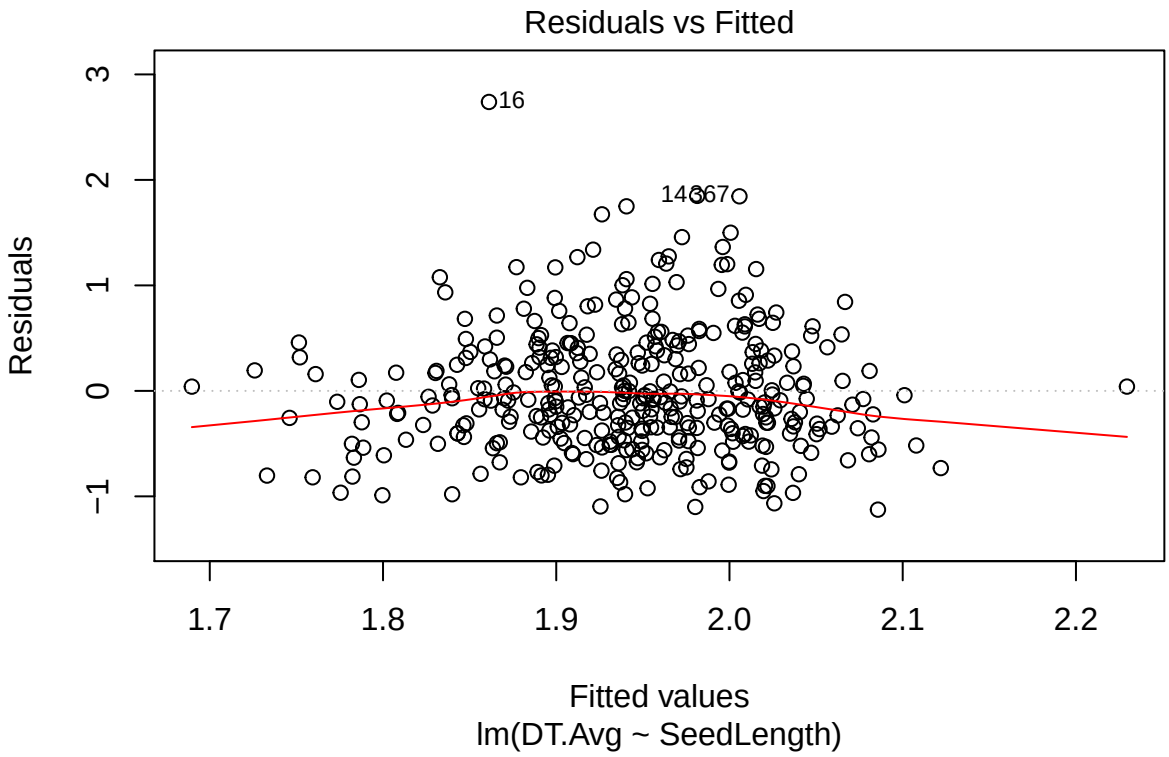

```
summary(mod.L)
```

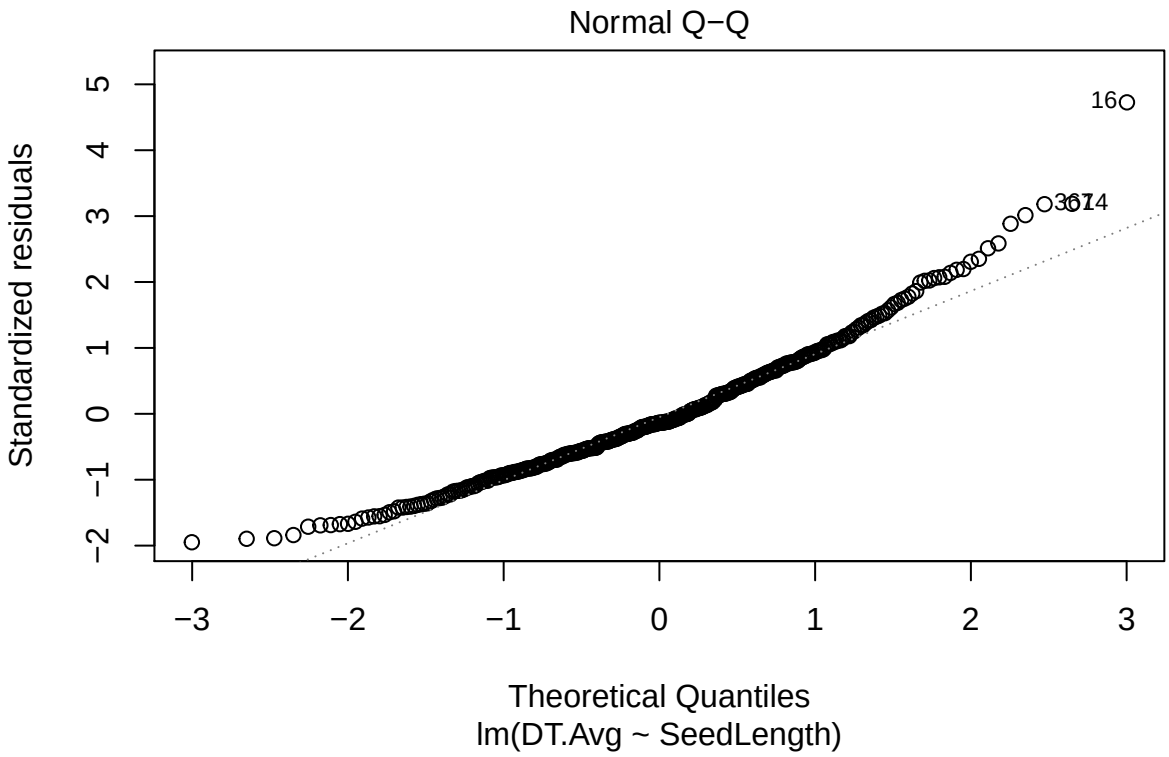
```
##
## Call:
## lm(formula = DT.Avg ~ SeedLength, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.12571 -0.40302 -0.07861  0.34512  2.73883
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  1.47616    0.18399   8.023 1.37e-14 ***
## 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
```

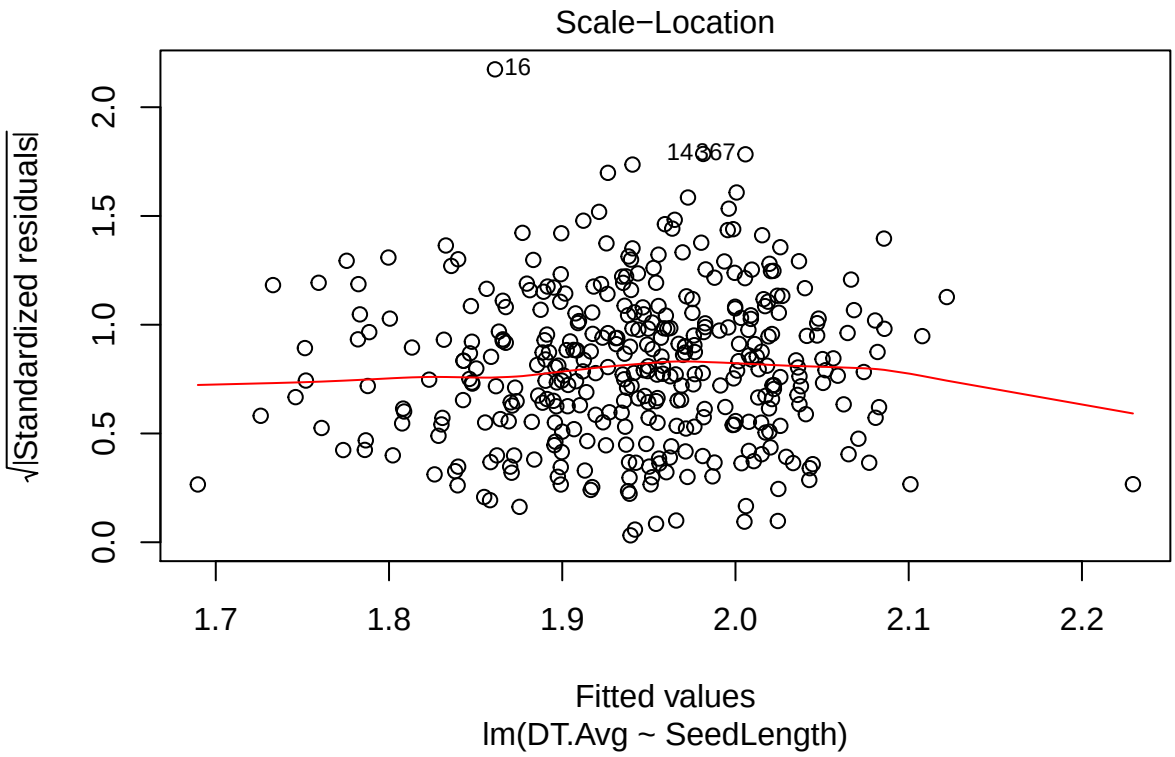
```
plot(rstandard(mod.L) ~ SeedLength, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```

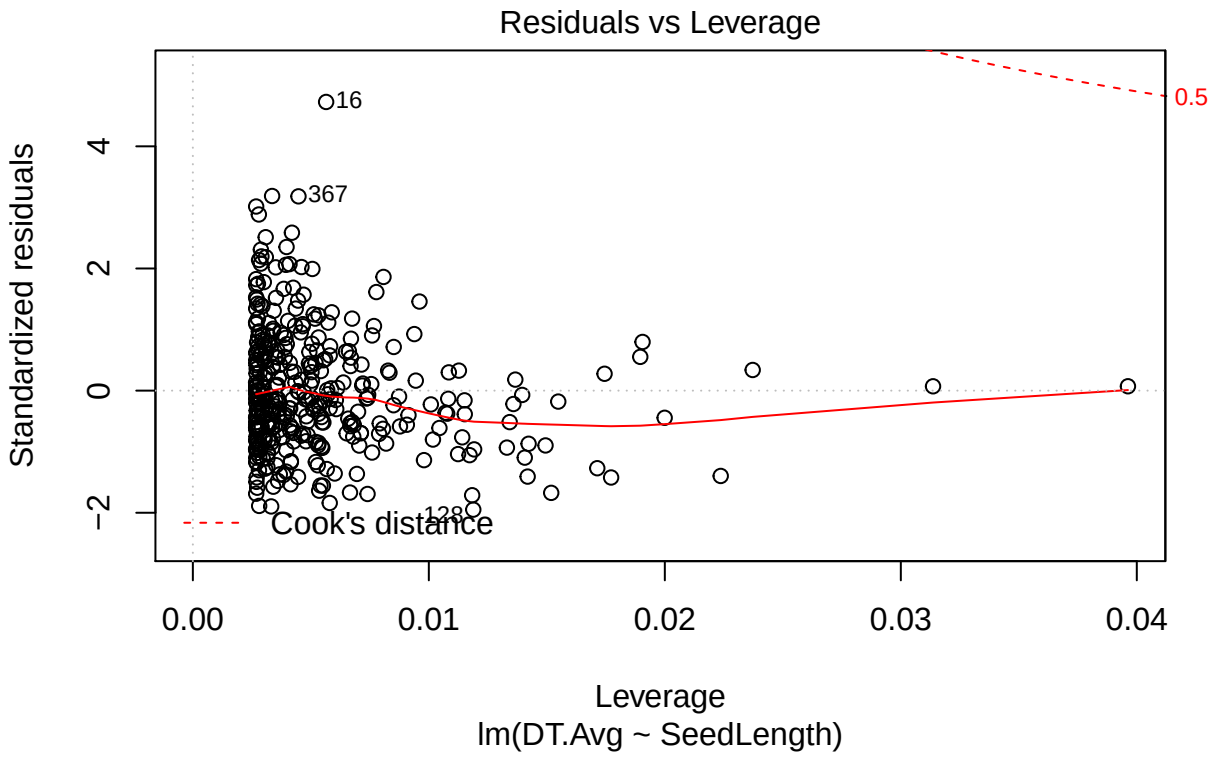



```
plot(mod.L, panel = panel.smooth)
```

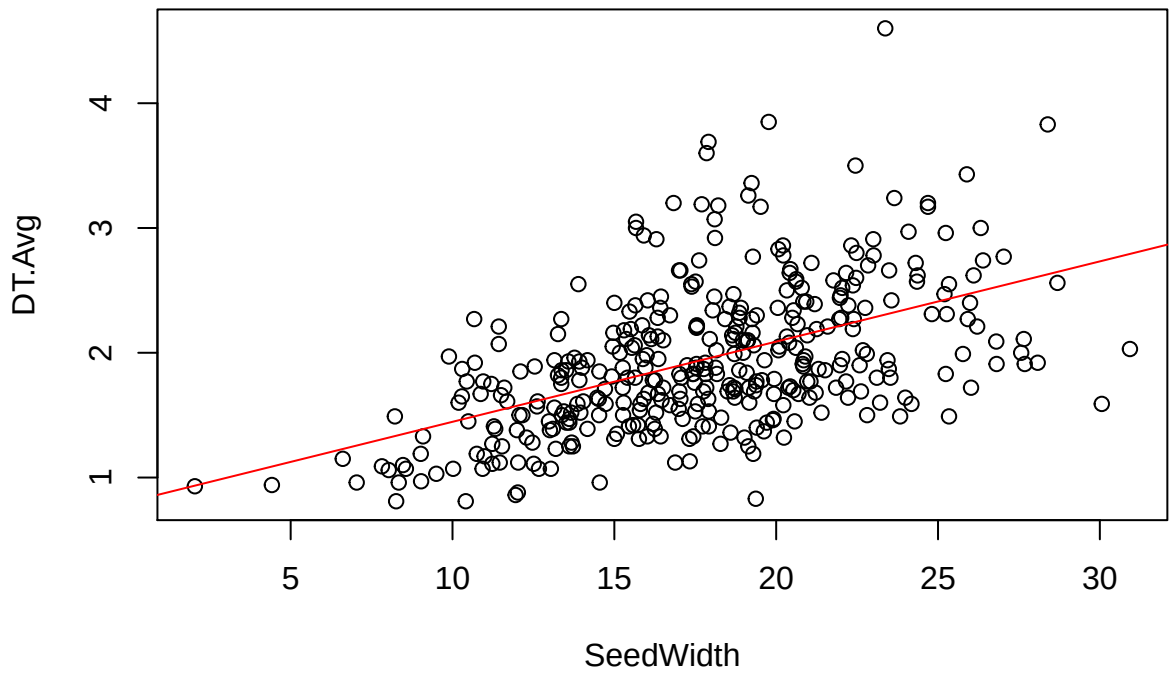

Residuals vs Fitted
Residuals
Fitted values
lm(DT.Avg ~ SeedLength)
16
143
67
3
2
1
0
−1
1.7
1.8
1.9
2.0
2.1
2.2


Normal Q−Q
Standardized residuals
Theoretical Quantiles
lm(DT.Avg ~ SeedLength)
16
367
374
−3
−2
−1
0
1
2
3
−2
−1
0
1
2
3
4
5


Scale−Location
16
143
67
√|Standardized residuals|
0.0
0.5
1.0
1.5
2.0
1.7
1.8
1.9
2.0
2.1
2.2
Fitted values
lm(DT.Avg ~ SeedLength)



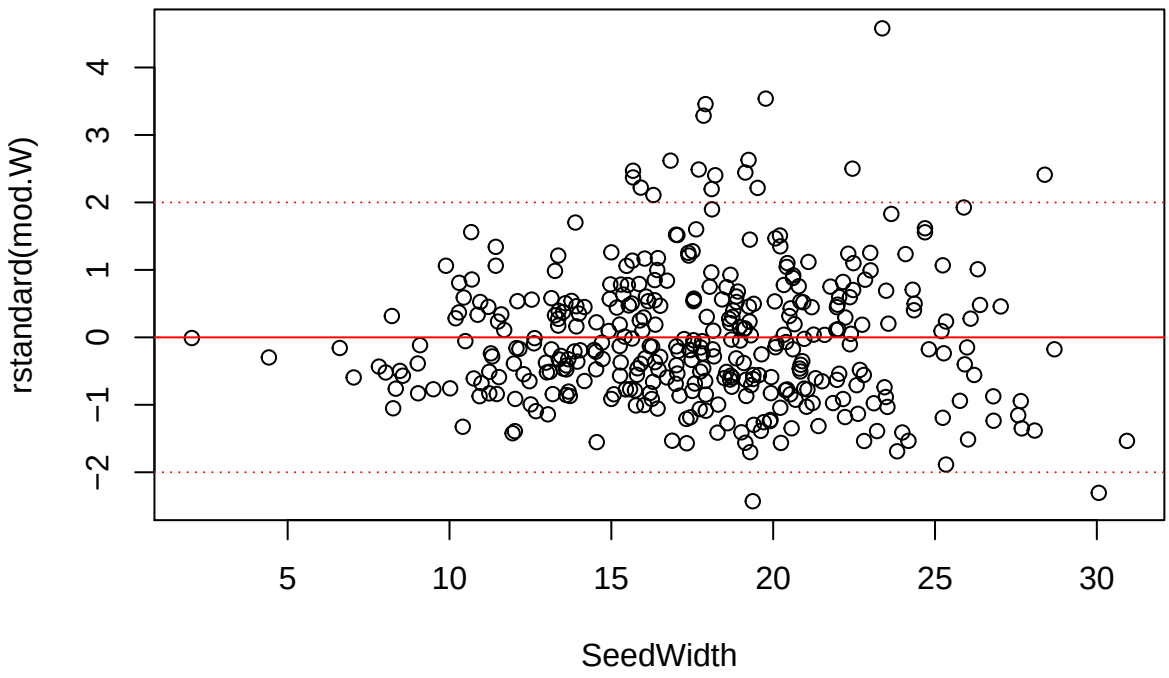

```r
# Average DT ~ pappus width
mod.W <- lm(DT.Avg ~ SeedWidth, data = data.new)
plot(DT.Avg ~ SeedWidth, data = data.new)
abline(mod.W, col = "red")
```



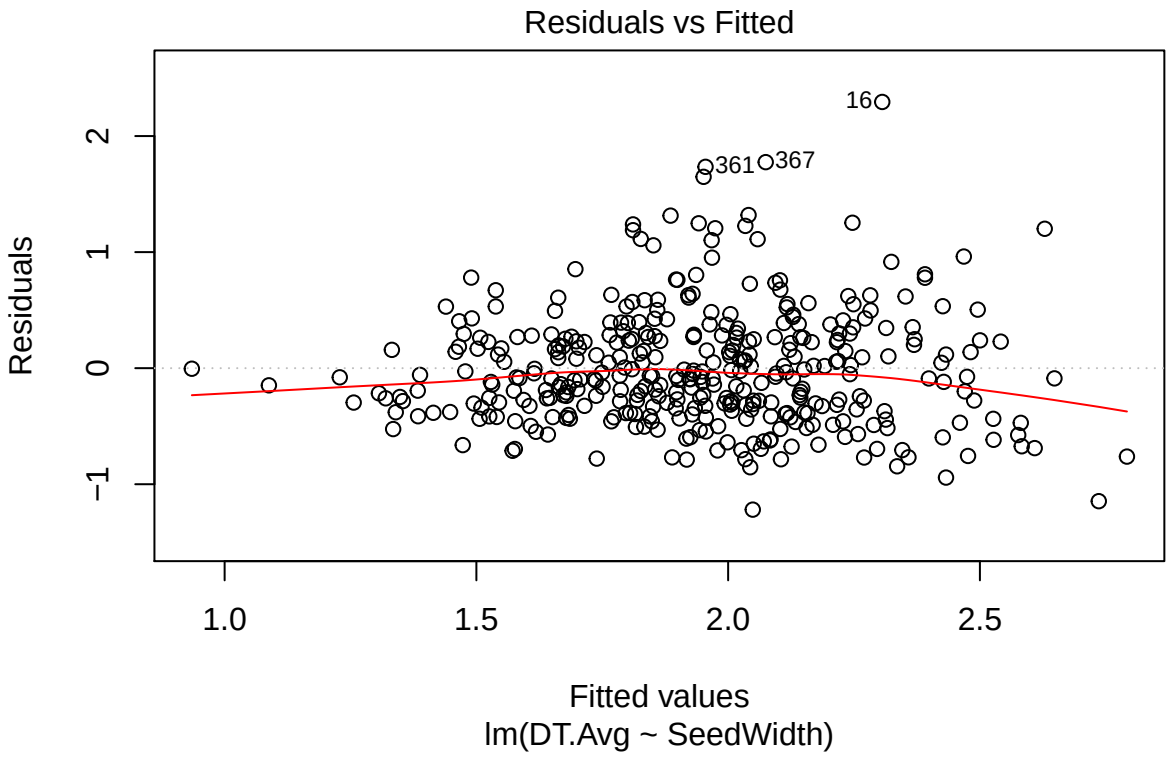

```
summary(mod.W)
```

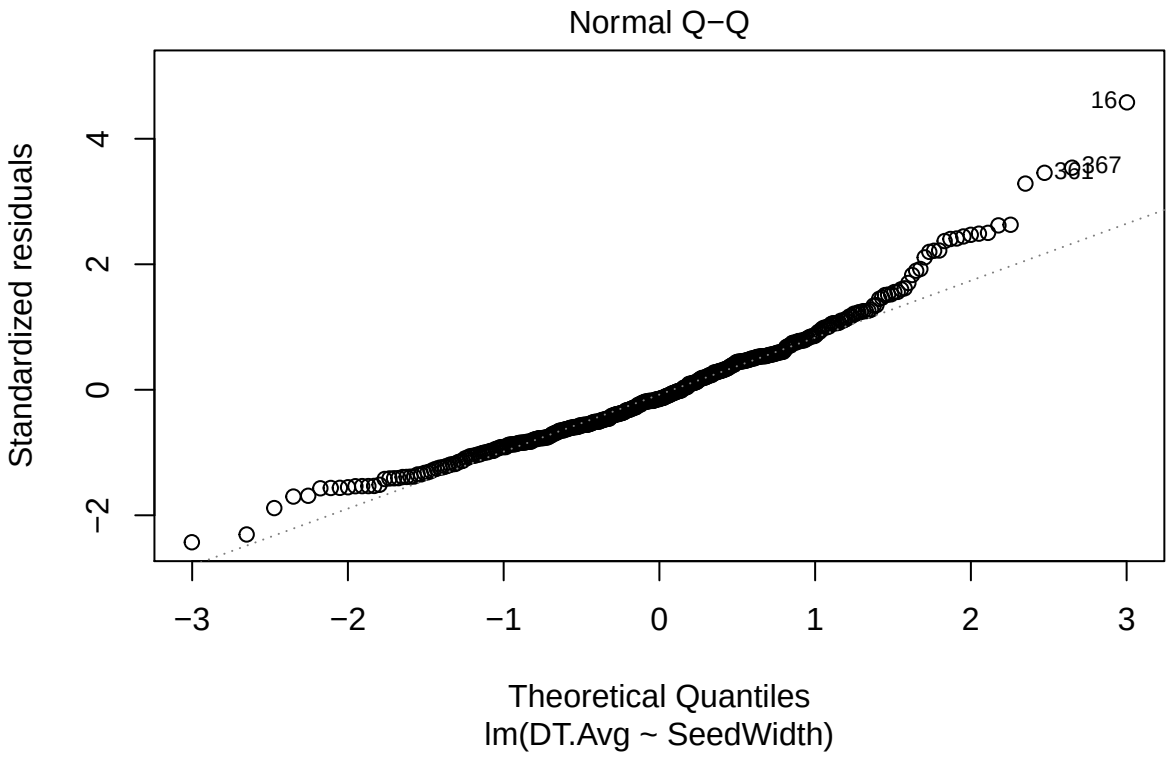
```
##
## Call:
## lm(formula = DT.Avg ~ SeedWidth, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.21893 -0.34594 -0.07393  0.26870  2.29394
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 0.803773   0.101777   7.897 3.26e-14 ***
## 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
```

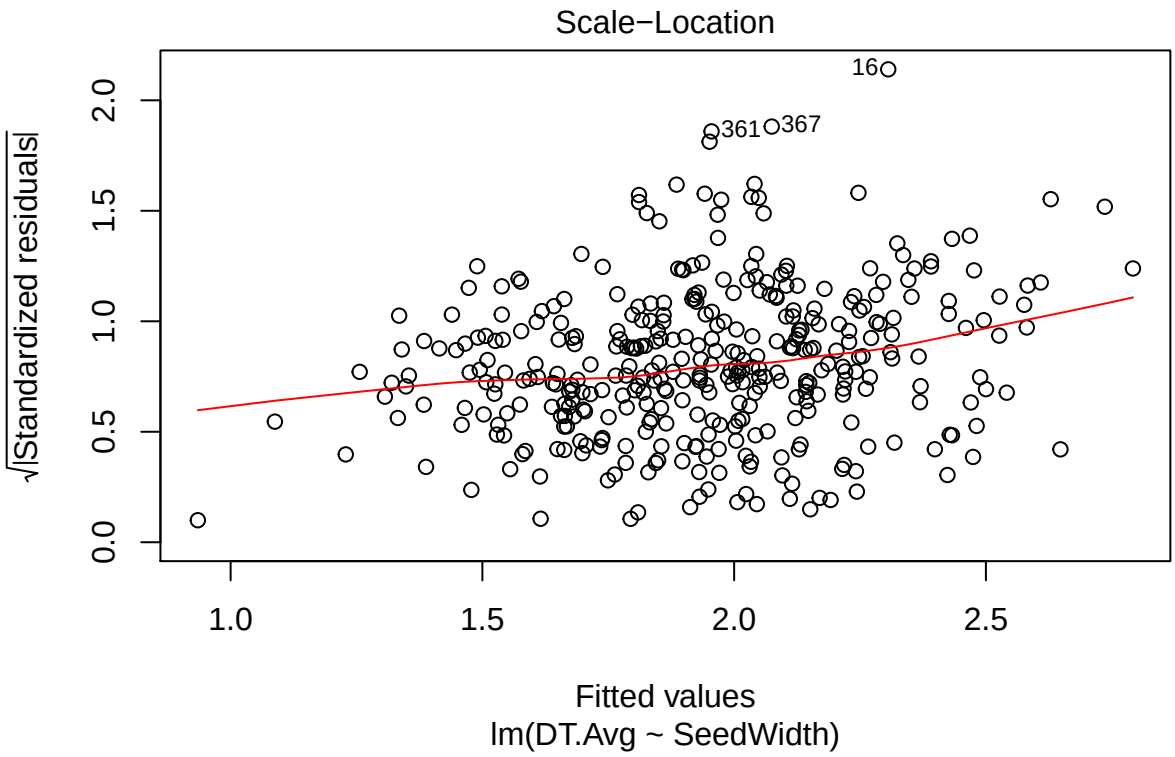
```
plot(rstandard(mod.W) ~ SeedWidth, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```

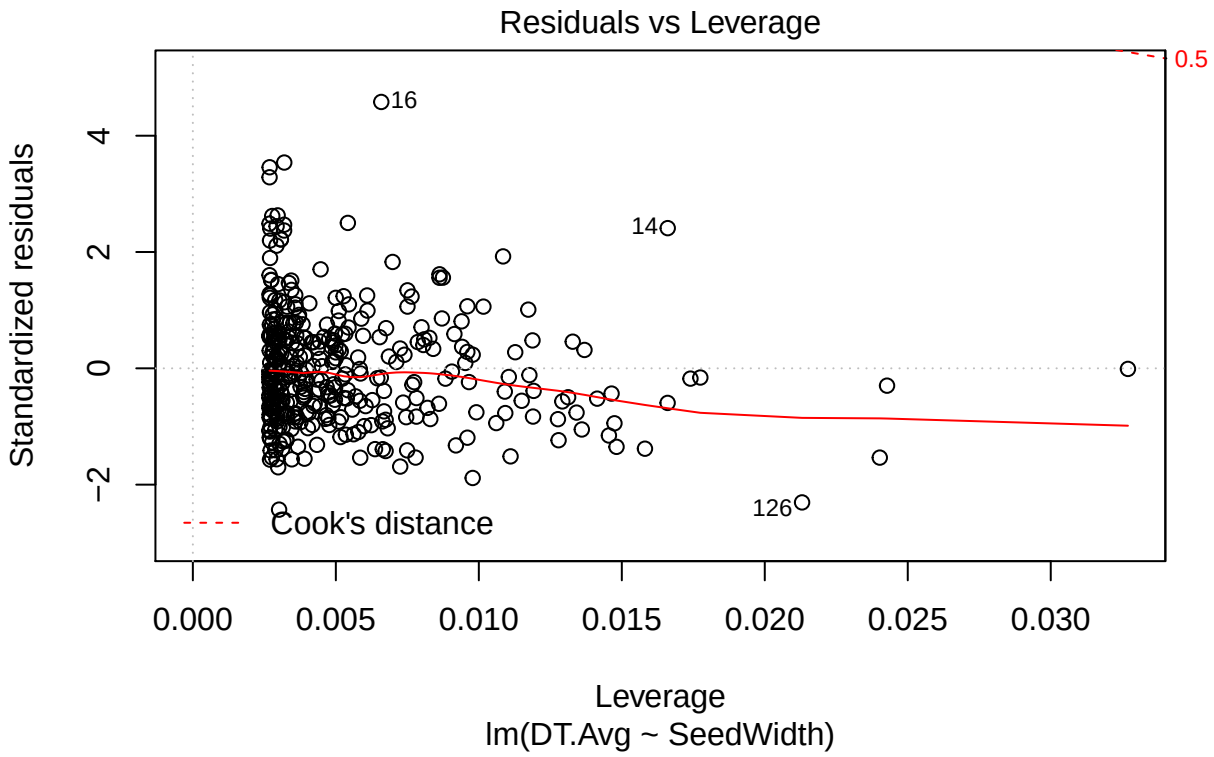



```
plot(mod.W)
```

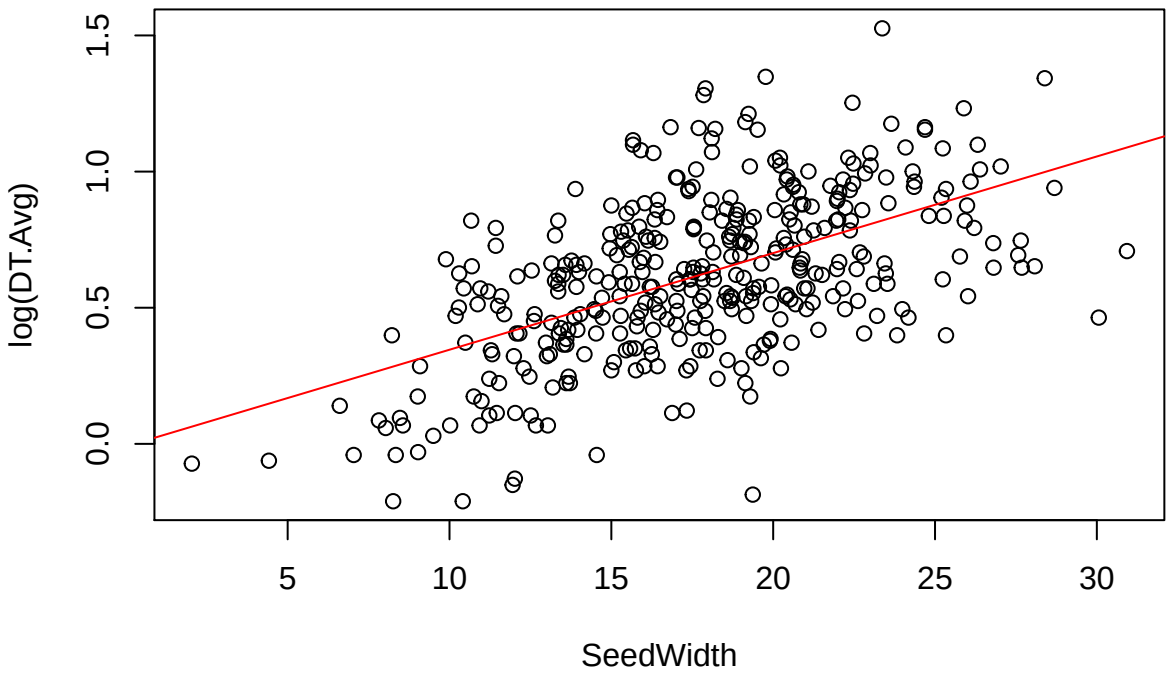

Residuals vs Fitted
16
361
367
Residuals
2
1
0
−1
1.0
1.5
2.0
2.5
Fitted values
lm(DT.Avg ~ SeedWidth)


Normal Q−Q
Standardized residuals
Theoretical Quantiles
lm(DT.Avg ~ SeedWidth)
16
267
301
−3
−2
−1
0
1
2
3
−2
0
2
4


Scale−Location
16
361
367
√|Standardized residuals|
0.0
0.5
1.0
1.5
2.0
1.0
1.5
2.0
2.5
Fitted values
lm(DT.Avg ~ SeedWidth)



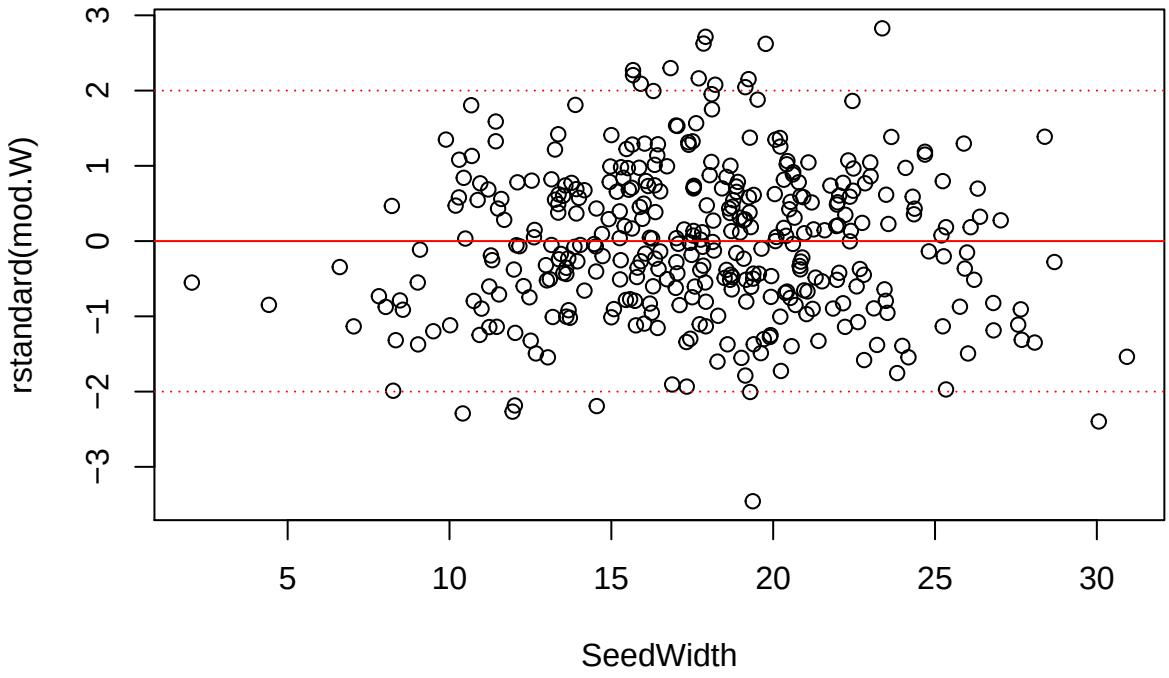

```
# Log-transformed average DT ~ pappus width
mod.W <- lm(log(DT.Avg) ~ SeedWidth, data = data.new)
plot(log(DT.Avg) ~ SeedWidth, data = data.new)
abline(mod.W, col = "red")
```



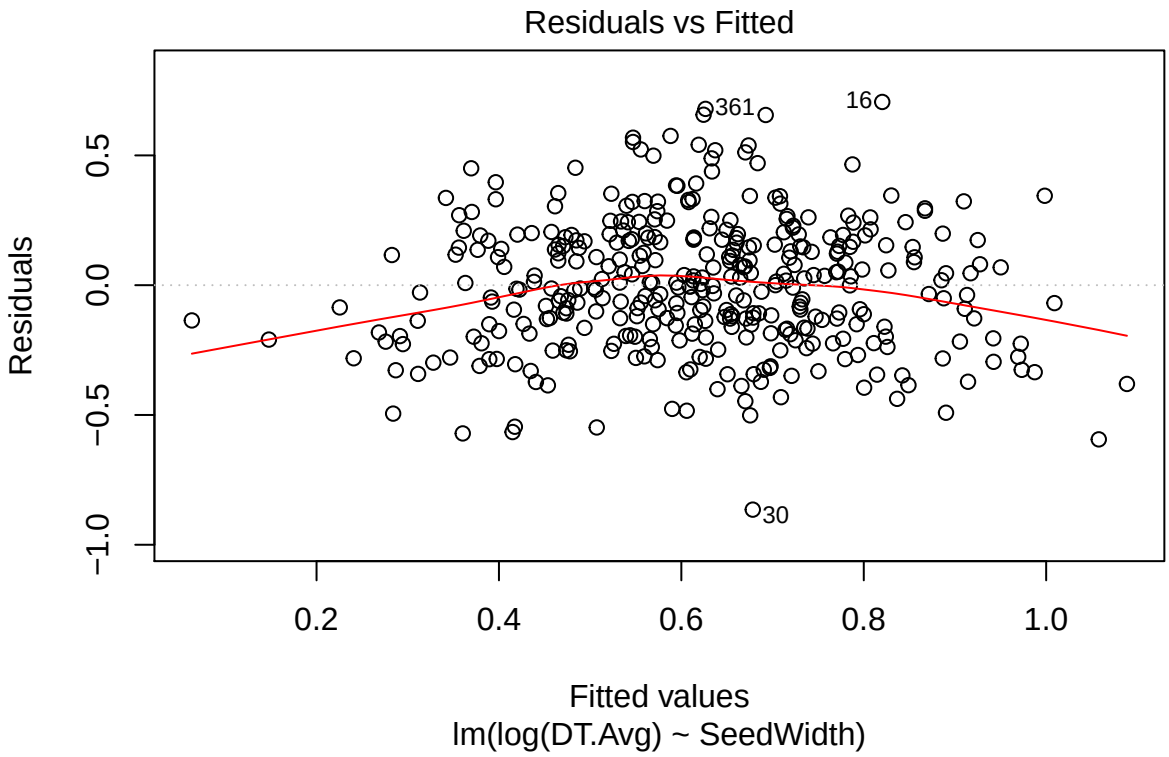

```
summary(mod.W)
```

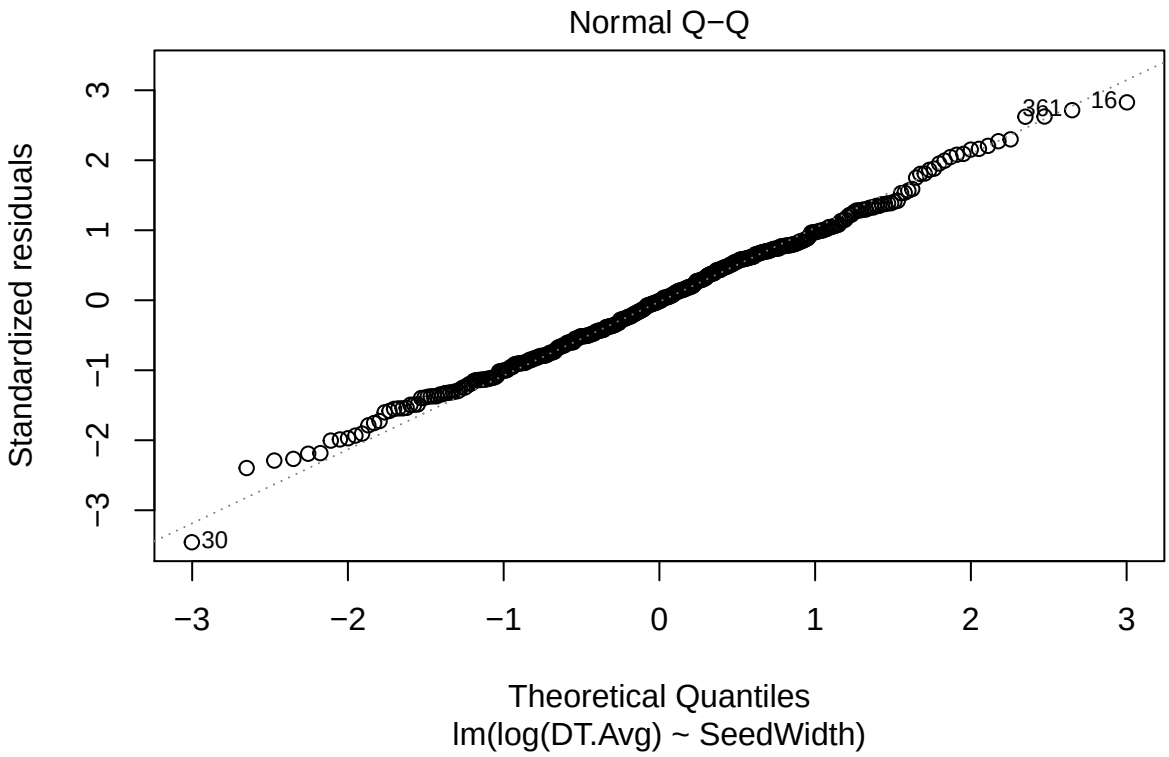
```
##
## Call:
## lm(formula = log(DT.Avg) ~ SeedWidth, data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.86464 -0.18224 -0.00303  0.17262  0.70579
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) -0.009110   0.050732   -0.18    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
```

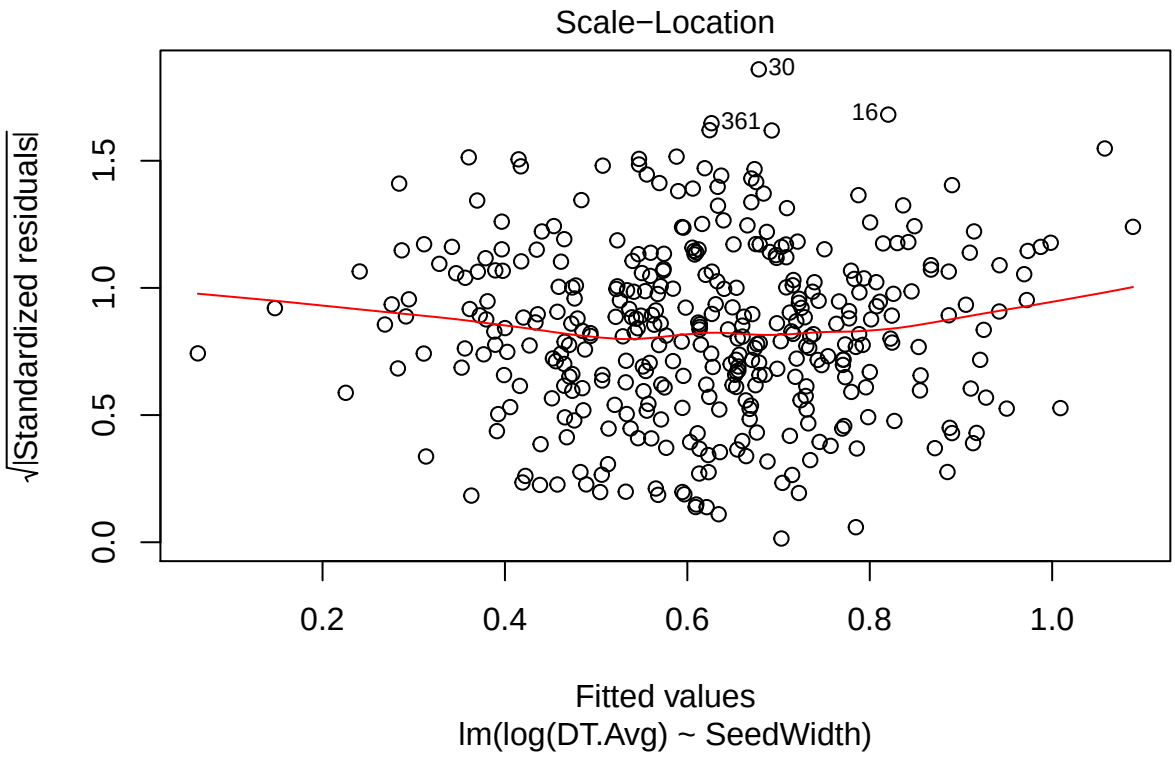
```
plot(rstandard(mod.W) ~ SeedWidth, data = data.new)
abline(h = 0, col = "red")
abline(h = c(-2, 2), col = "red", lty = 3)
```

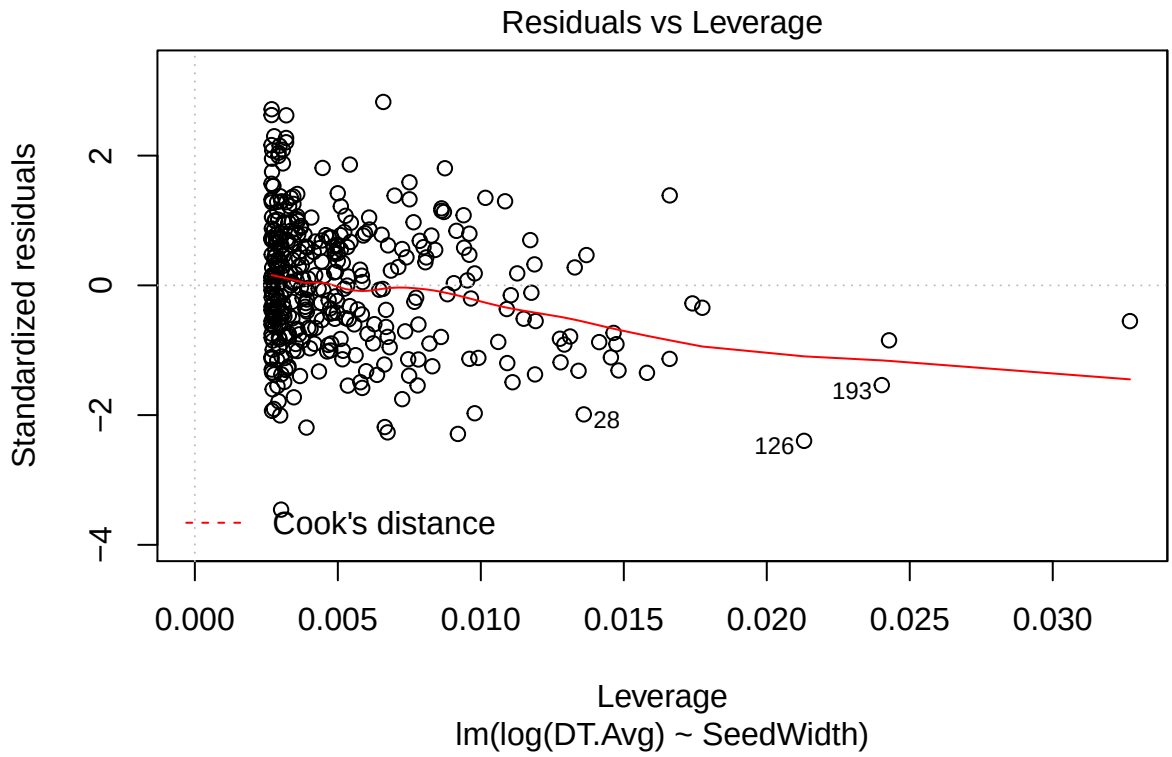



```
plot(mod.W)
```

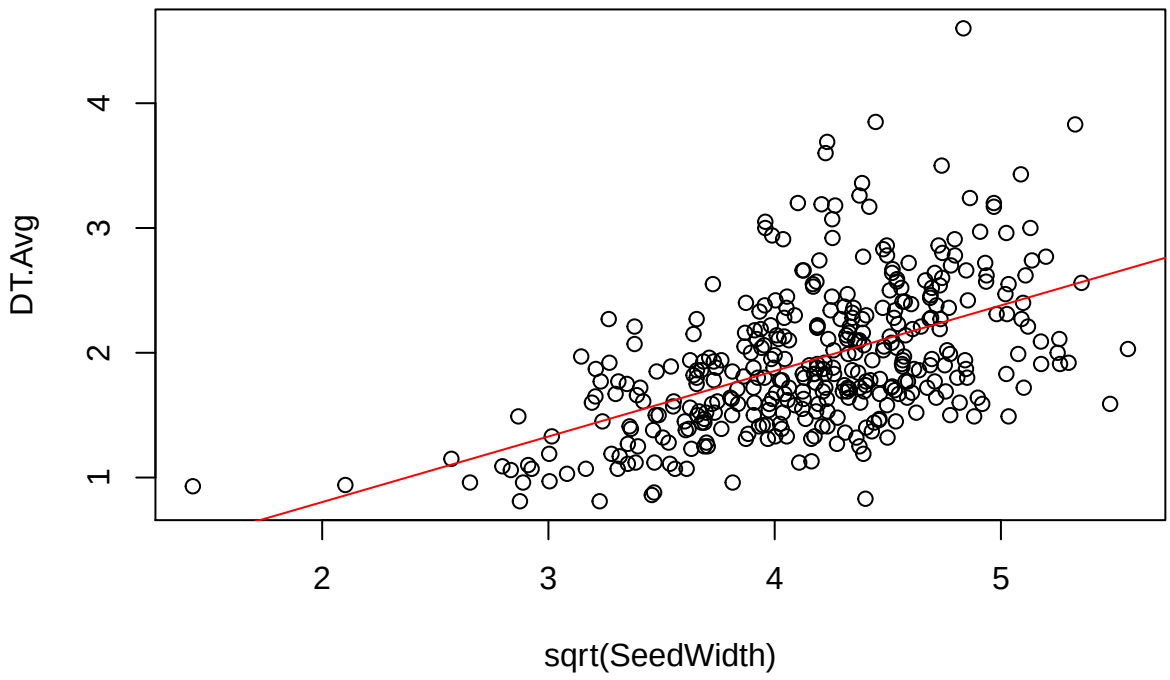

Residuals vs Fitted
Residuals
Fitted values
lm(log(DT.Avg) ~ SeedWidth)
361
16
30
0.5
0.0
−0.5
−1.0
0.2
0.4
0.6
0.8
1.0


Normal Q−Q
Standardized residuals
Theoretical Quantiles
lm(log(DT.Avg) ~ SeedWidth)
30
361
16
−3
−2
−1
0
1
2
3


Scale−Location
30
361
16
√|Standardized residuals|
0.0
0.5
1.0
1.5
0.2
0.4
0.6
0.8
1.0
Fitted values
lm(log(DT.Avg) ~ SeedWidth)



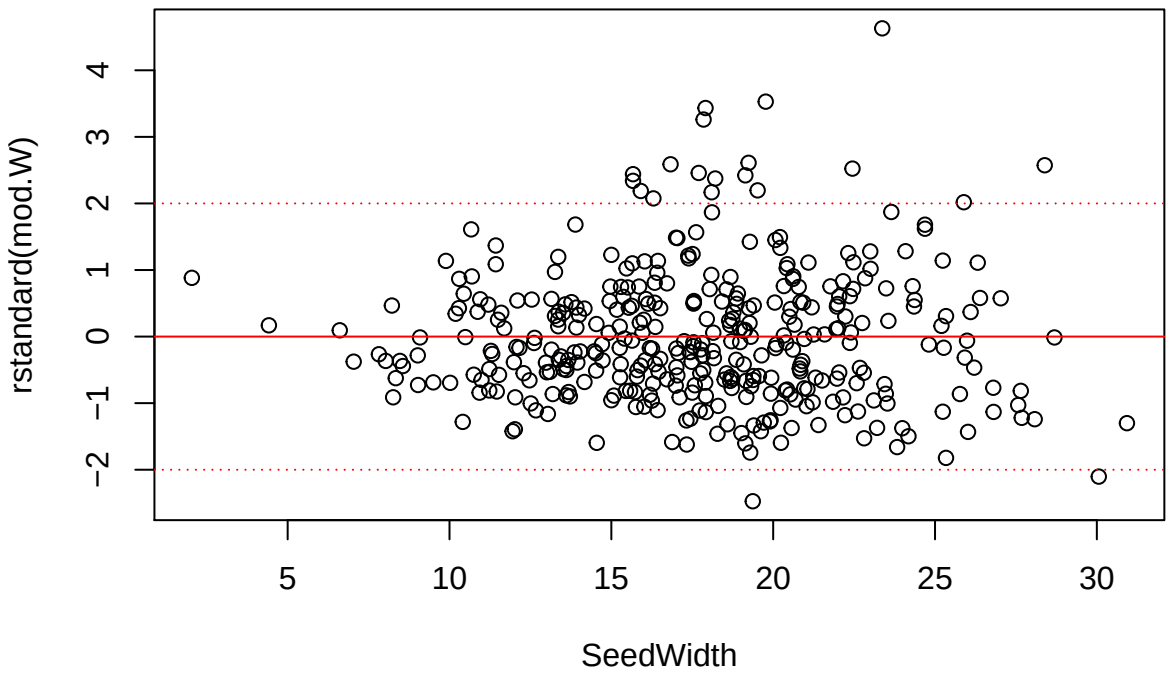

```
# Square-root average DT ~ pappus width
mod.W <- lm(DT.Avg ~ sqrt(SeedWidth), data = data.new)
plot(DT.Avg ~ sqrt(SeedWidth), data = data.new)
abline(mod.W, col = "red")
```



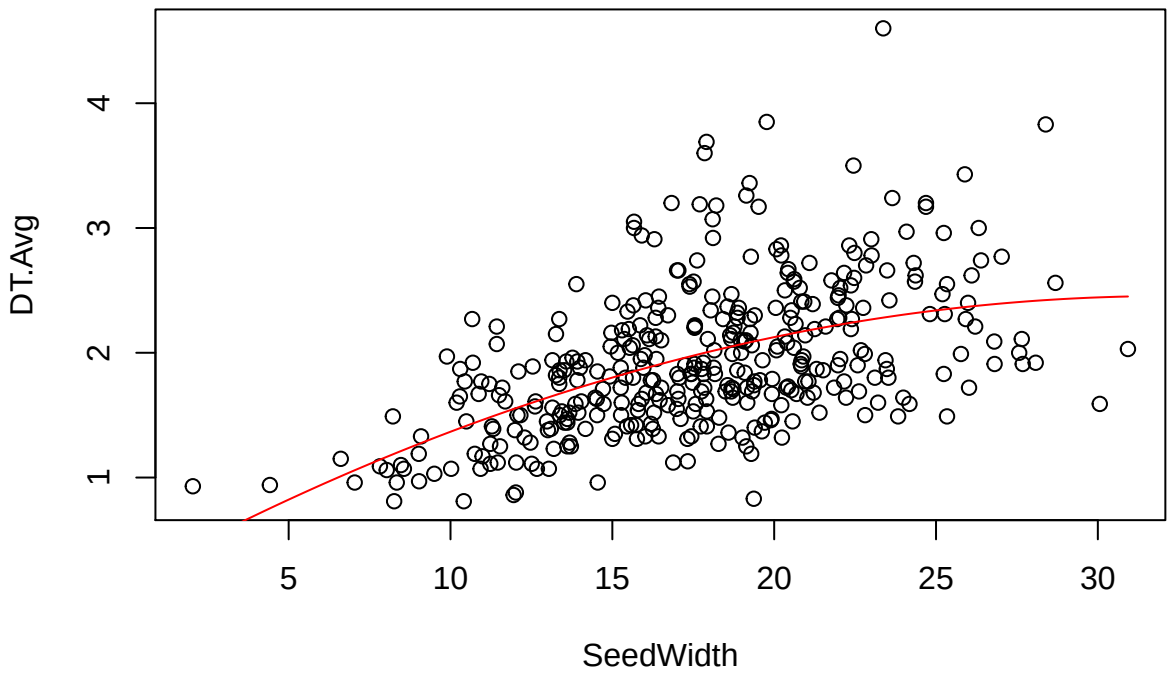

```
summary(mod.W)
```

```
##
## 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)
```

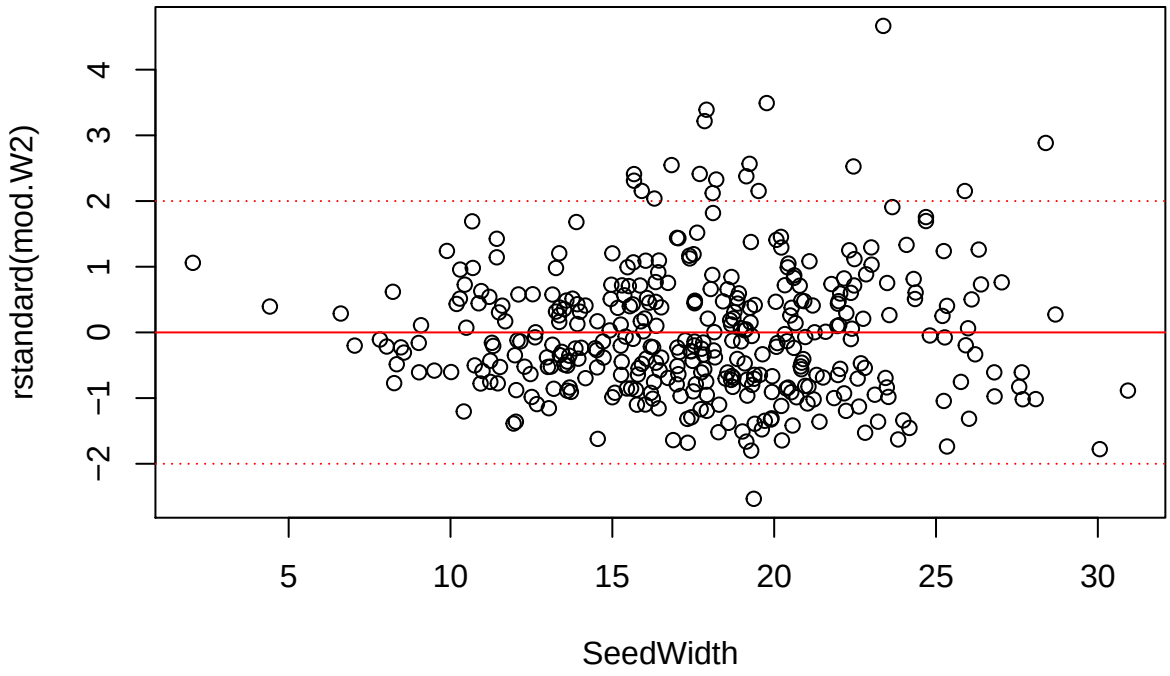
```
##
## Call:
## lm(formula = DT.Avg ~ SeedWidth + I(SeedWidth^2), data = data.new)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.26051 -0.34955 -0.06896  0.25893  2.31826
##
## Coefficients:
##                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)     0.1688639  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)
```

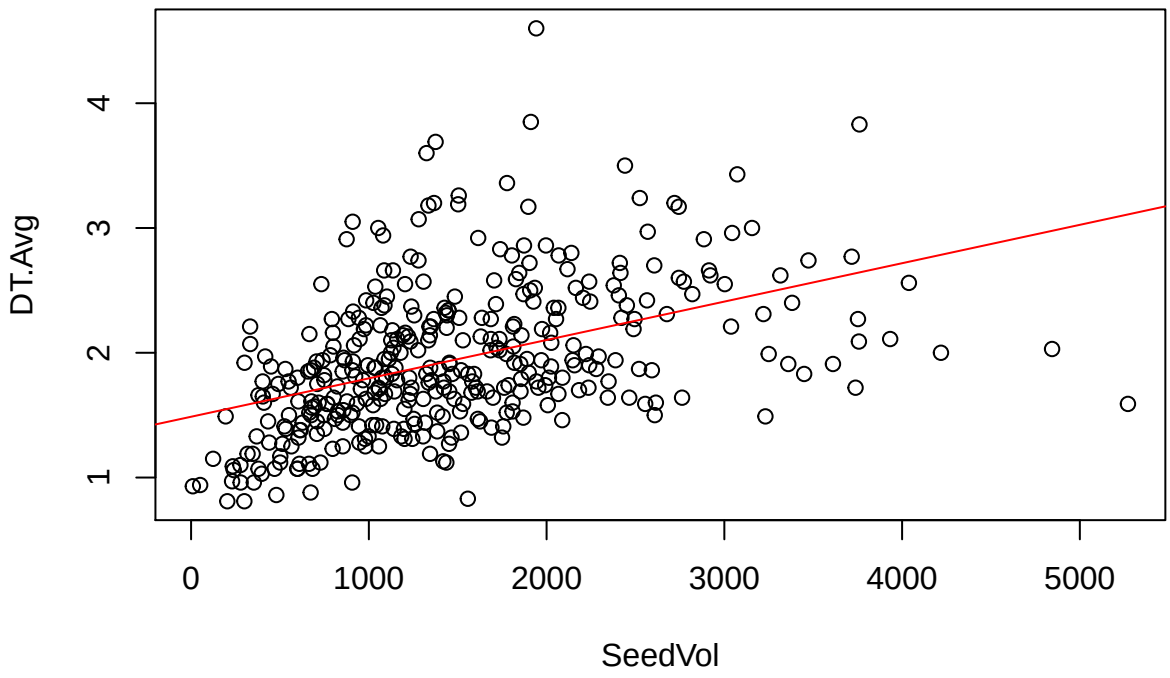
```
## Analysis of Variance Table
##
## Model 1: DT.Avg ~ sqrt(SeedWidth)
```

```
## 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
```

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



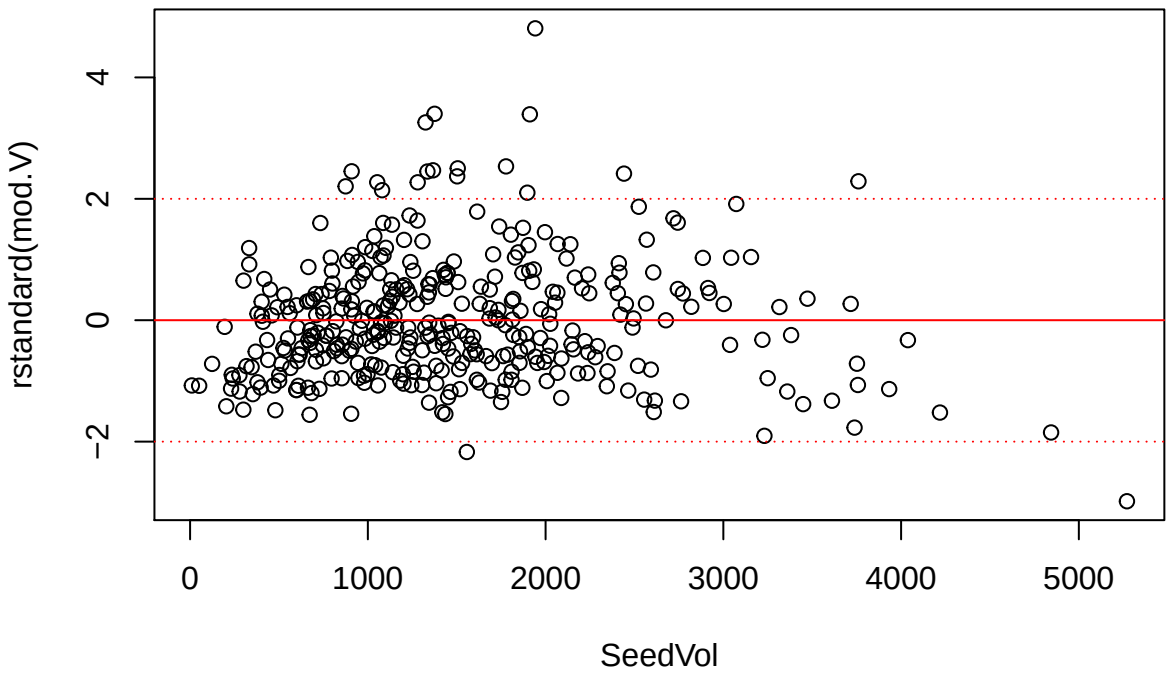

```r
# Average DT ~ pappus conical volume
mod.V <- lm(DT.Avg ~ SeedVol, data = data.new)
plot(DT.Avg ~ SeedVol, data = data.new)
abline(mod.V, col = "red")
```



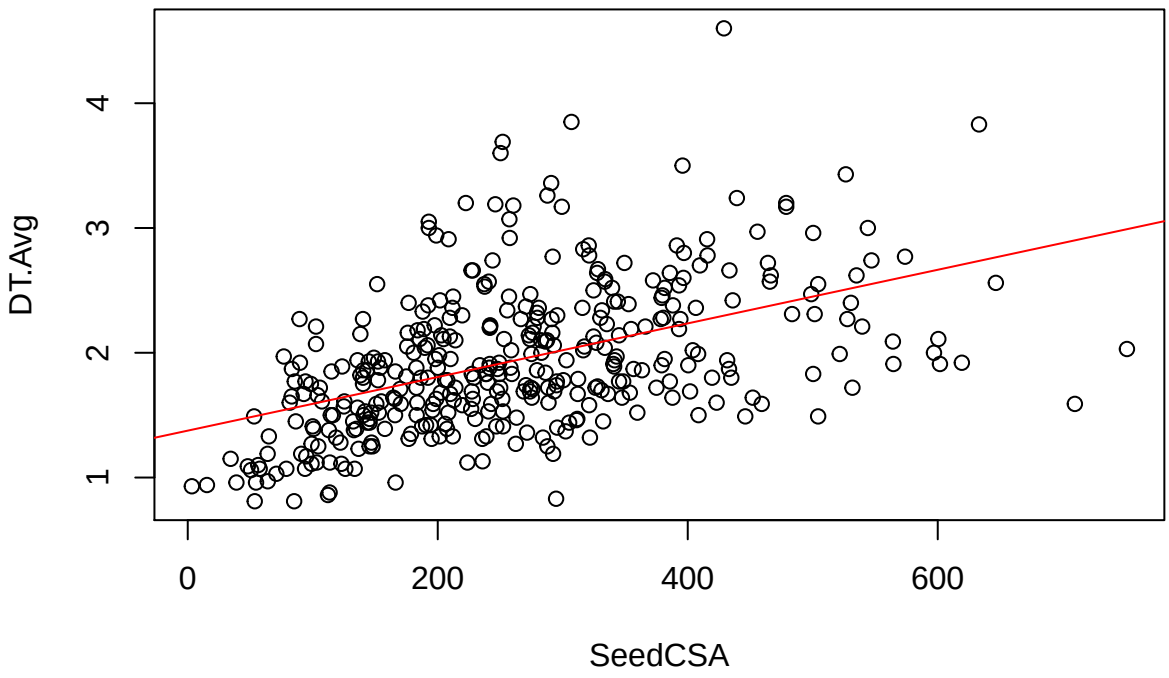

```
summary(mod.V)
```

```
##
## 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)
```



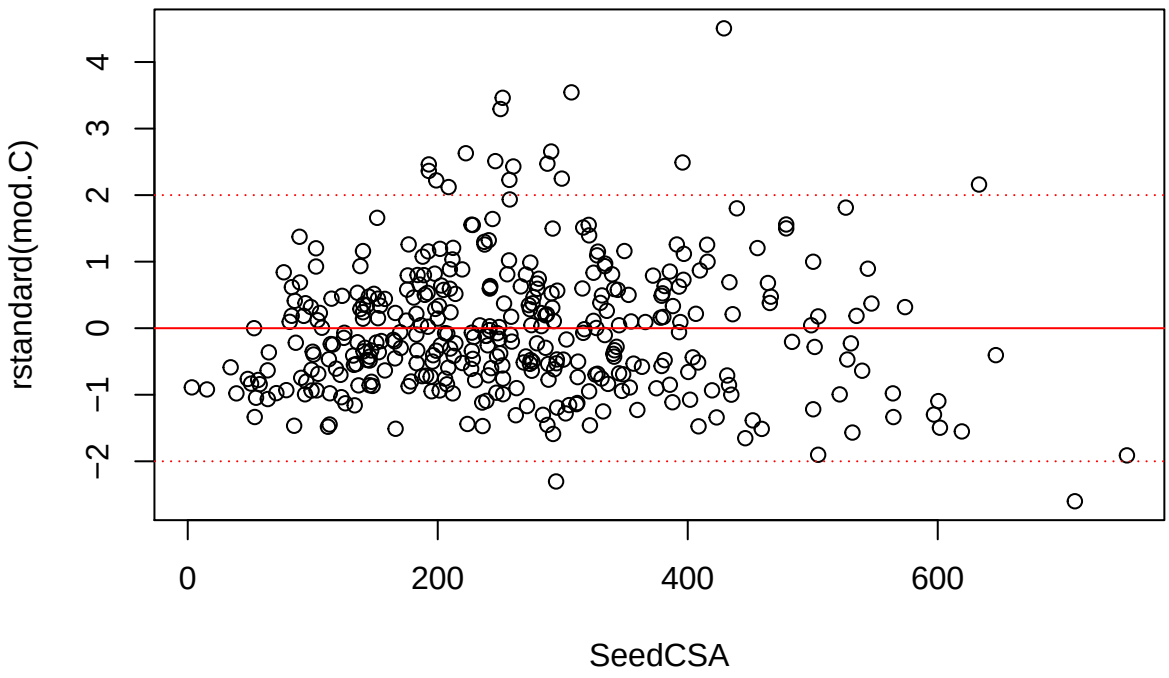

```
# Average DT ~ pappus max circular CSA
mod.C <- lm(DT.Avg ~ SeedCSA, data = data.new)
plot(DT.Avg ~ SeedCSA, data = data.new)
abline(mod.C, col = "red")
```




```
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
```

```r
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
```