

DASC 6510 Project ANOVA Models

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Split-Split-Plot ANOVA

The experiment was conducted using three blocks to control for field variability. Treatments were randomized within each block following a split-split-plot design.

The structure of the experimental design was as follows:

- Main plot factor: Planting date (5 levels: July 16, August 1, August 16, September 1, September 16)
- Subplot factor: Rice genotype (3 varieties: Nehara, Bhasamanik, Bhasakalma)
- Sub-subplot factors: Plant spacing (6 in, 9 in, 12 in) and number of seedlings per hill (1, 2, and local method)

It was determined that a split-split-plot ANOVA model should be fitted to the data, as a standard ANOVA model might not be adequate. The *lmer* function from the *lme4* package will be used to fit the model.

```
# Loading the lme4 package
library(lmerTest)
```

```
## Loading required package: lme4
```

```
## Loading required package: Matrix
```

```
##
```

```
## Attaching package: 'lmerTest'
```

```
## The following object is masked from 'package:lme4':
```

```
##
```

```
##      lmer
```

```
## The following object is masked from 'package:stats':
```

```
##
```

```
##      step
```

```
## Fitting the mixed-effects model ##
```

```
# Fixed effects include all factors and their interactions.
```

```
# Random effects capture the appropriate
```

```
# error structures for each plot size.
```

```
splitSplitAnova_fit <- lmer(yield ~ date * variety * seed * spacing +
```

```

      (1 | block) +
      (1 | block:date) +
      (1 | block:date:variety),
data = df)
anova(splitSplitAnova_fit)

```

```

## Type III Analysis of Variance Table with Satterthwaite's method
##
##      Sum Sq Mean Sq NumDF DenDF  F value    Pr(>F)
## date      426381   106595      4      8  78.4703 1.870e-06 ***
## variety    326478   163239      2     20 120.1686 7.161e-12 ***
## seed        65375    32687      2    240  24.0629 2.989e-10 ***
## spacing    129705   64852      2    240  47.7413 < 2.2e-16 ***
## date:variety    54569    6821      8     20   5.0214 0.0016073 **
## date:seed      19883    2485      8    240   1.8296 0.0722917 .
## variety:seed     4449    1112      4    240   0.8189 0.5141991
## date:spacing    42571    5321      8    240   3.9174 0.0002276 ***
## variety:spacing   5213    1303      4    240   0.9593 0.4305374
## seed:spacing     5574    1394      4    240   1.0259 0.3945266
## date:variety:seed  63885    3993     16    240   2.9393 0.0001857 ***
## date:variety:spacing 47251    2953     16    240   2.1740 0.0065104 **
## date:seed:spacing  23059    1441     16    240   1.0609 0.3937950
## variety:seed:spacing  9584    1198      8    240   0.8819 0.5323336
## date:variety:seed:spacing 30288     946     32    240   0.6968 0.8896726
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

# Updating the model formula to remove the highest-order
# non-significant interaction term:
# - date:variety:seed:spacing
splitSplitAnova2 <- update(splitSplitAnova_fit, ~.
  -date:variety:seed:spacing)
anova(splitSplitAnova2)

```

```

## Type III Analysis of Variance Table with Satterthwaite's method
##
##      Sum Sq Mean Sq NumDF DenDF  F value    Pr(>F)
## date      411169   102792      4      8  78.4702 1.870e-06 ***
## variety    314831   157416      2     20 120.1688 7.160e-12 ***
## seed        65375    32687      2    272  24.9531 1.122e-10 ***
## spacing    129705   64852      2    272  49.5074 < 2.2e-16 ***
## date:variety    52623    6578      8     20   5.0214 0.0016073 **
## date:seed      19883    2485      8    272   1.8973 0.0604901 .
## variety:seed     4449    1112      4    272   0.8492 0.4951088
## date:spacing    42571    5321      8    272   4.0623 0.0001386 ***
## variety:spacing   5213    1303      4    272   0.9948 0.4107872
## seed:spacing     5574    1394      4    272   1.0638 0.3747701
## date:variety:seed  63885    3993     16    272   3.0480 9.771e-05 ***
## date:variety:spacing 47251    2953     16    272   2.2544 0.0043273 **
## date:seed:spacing  23059    1441     16    272   1.1002 0.3545443
## variety:seed:spacing  9584    1198      8    272   0.9145 0.5047689
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

# Updating the model formula to remove non-significant
# 3-way interaction terms:
#   - variety:seed:spacing
#   - date:seed:spacing
splitSplitAnova3 <- update(splitSplitAnova2, .~.
                           -variety:seed:spacing
                           -date:seed:spacing)
anova(splitSplitAnova3)

```

```

## Type III Analysis of Variance Table with Satterthwaite's method
##
##           Sum Sq Mean Sq NumDF DenDF  F value    Pr(>F)
## date           412448   103112     4      8  78.4706 1.870e-06 ***
## variety         315808   157904     2     20 120.1688 7.160e-12 ***
## seed            65375    32687     2    296  24.8759 1.033e-10 ***
## spacing        129705    64852     2    296  49.3542 < 2.2e-16 ***
## date:variety     52786     6598     8     20   5.0214 0.0016073 **
## date:seed        19883     2485     8    296   1.8914 0.0610042 .
## variety:seed      4449     1112     4    296   0.8465 0.4966250
## date:spacing     42571     5321     8    296   4.0497 0.0001375 ***
## variety:spacing   5213     1303     4    296   0.9917 0.4122963
## seed:spacing      5574     1394     4    296   1.0605 0.3762520
## date:variety:seed 63885     3993    16    296   3.0386 9.529e-05 ***
## date:variety:spacing 47251     2953    16    296   2.2474 0.0043292 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

```

# Updating the model formula to remove non-significant
# 2-way interaction terms:
#   - seed:spacing
#   - variety:spacing
#   - variety:seed
splitSplitAnova4 <- update(splitSplitAnova3, .~.
                           -seed:spacing
                           -variety:spacing
                           -variety:seed)
anova(splitSplitAnova4)

```

```

## Type III Analysis of Variance Table with Satterthwaite's method
##
##           Sum Sq Mean Sq NumDF DenDF  F value    Pr(>F)
## date           427283   106821     4   10.03  81.2276 1.339e-07 ***
## variety         316064   158032     2   20.00 120.1690 7.160e-12 ***
## seed            65375    32687     2 300.00  24.8559 1.027e-10 ***
## spacing        129705    64852     2 300.00  49.3144 < 2.2e-16 ***
## date:variety     33277     4160     8   68.00   3.1630 0.0041865 **
## date:seed        18579     2322     8 300.00   1.7660 0.0832838 .
## date:spacing     31352     3919     8 300.00   2.9800 0.0031555 **
## date:variety:seed 68334     3417    20 300.00   2.5981 0.0002758 ***
## date:variety:spacing 52463     2623    20 300.00   1.9947 0.0075579 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

The final reduced model includes the following terms:

- date
- variety
- seed
- spacing
- date:variety
- date:seed
- date:spacing
- date:variety:seed
- date:variety:spacing

Note that the p-value associated with the date:seed interaction is given by

0.0832838.

Despite being greater than $\alpha = 0.05$, I decided to keep this term in the model as it was very close.

```
# The final reduced split-split-plot ANOVA model
```

```
splitSplitAnova_reduced <- splitSplitAnova4
anova(splitSplitAnova_reduced)
```

```
## Type III Analysis of Variance Table with Satterthwaite's method
##              Sum Sq Mean Sq NumDF   DenDF    F value    Pr(>F)
## date          427283  106821     4    10.03   81.2276 1.339e-07 ***
## variety       316064  158032     2    20.00  120.1690 7.160e-12 ***
## seed          65375   32687     2  300.00   24.8559 1.027e-10 ***
## spacing       129705   64852     2  300.00   49.3144 < 2.2e-16 ***
## date:variety   33277    4160     8    68.00    3.1630 0.0041865 **
## date:seed      18579    2322     8  300.00    1.7660 0.0832838 .
## date:spacing   31352    3919     8  300.00    2.9800 0.0031555 **
## date:variety:seed 68334    3417    20  300.00    2.5981 0.0002758 ***
## date:variety:spacing 52463    2623    20  300.00    1.9947 0.0075579 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Split-Split-Plot Regression Model

```
# Regression model with coefficients
```

```
summary(splitSplitAnova_reduced)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: yield ~ date + variety + seed + spacing + (1 | block) + (1 |
##      block:date) + (1 | block:date:variety) + date:variety + date:seed +
##      date:spacing + date:variety:seed + date:variety:spacing
## Data: df
```

```

##
## REML criterion at convergence: 3519.3
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -4.9659 -0.4270 -0.0118  0.3546  3.8656
##
## Random effects:
##   Groups             Name             Variance Std.Dev.
## block:date:variety (Intercept)    509.0    22.56
## block:date          (Intercept)    909.6    30.16
## block               (Intercept)    841.4    29.01
## Residual                        1315.1    36.26
## Number of obs: 405, groups:  block:date:variety, 45; block:date, 15; block, 3
##
## Fixed effects:
##
##              Estimate Std. Error      df t value
## (Intercept)    484.3148    31.5732   13.1192  15.339
## dateA16        -49.3889    37.8520   27.2163  -1.305
## dateJ16        -26.9444    37.8520   27.2163  -0.712
## dateS01        -64.3519    37.8520   27.2163  -1.700
## dateS16       -483.7222    37.8520   27.2163 -12.779
## varietyBhasamanik    61.6667    28.7470   67.9995   2.145
## varietyNehara    -106.6667    28.7470   67.9995  -3.711
## seed2             0.2778    17.0950  300.0000   0.016
## seedlocal         25.6111    17.0950  300.0000   1.498
## spacing9          19.2222    17.0950  300.0000   1.124
## spacing12        -10.5000    17.0950  300.0000  -0.614
## dateA16:varietyBhasamanik    7.4444    40.6544   67.9995   0.183
## dateJ16:varietyBhasamanik   -33.2222    40.6544   67.9995  -0.817
## dateS01:varietyBhasamanik   -37.5185    40.6544   67.9995  -0.923
## dateS16:varietyBhasamanik   100.7963    40.6544   67.9995   2.479
## dateA16:varietyNehara     45.5556    40.6544   67.9995   1.121
## dateJ16:varietyNehara     44.6481    40.6544   67.9995   1.098
## dateS01:varietyNehara    -46.8704    40.6544   67.9995  -1.153
## dateS16:varietyNehara    111.8889    40.6544   67.9995   2.752
## dateA16:seed2           58.7778    24.1760  300.0000   2.431
## dateJ16:seed2           32.5000    24.1760  300.0000   1.344
## dateS01:seed2            8.6111    24.1760  300.0000   0.356
## dateS16:seed2          -0.6111    24.1760  300.0000  -0.025
## dateA16:seedlocal       40.5556    24.1760  300.0000   1.678
## dateJ16:seedlocal       -1.3333    24.1760  300.0000  -0.055
## dateS01:seedlocal       15.7778    24.1760  300.0000   0.653
## dateS16:seedlocal      -25.8889    24.1760  300.0000  -1.071
## dateA16:spacing9       -27.5556    24.1760  300.0000  -1.140
## dateJ16:spacing9       -39.7222    24.1760  300.0000  -1.643
## dateS01:spacing9      -57.7222    24.1760  300.0000  -2.388
## dateS16:spacing9      -19.5000    24.1760  300.0000  -0.807
## dateA16:spacing12      -30.2778    24.1760  300.0000  -1.252
## dateJ16:spacing12      -32.2778    24.1760  300.0000  -1.335
## dateS01:spacing12     -92.0556    24.1760  300.0000  -3.808
## dateS16:spacing12      10.8333    24.1760  300.0000   0.448
## dateA01:varietyBhasamanik:seed2    1.4444    24.1760  300.0000   0.060
## dateA16:varietyBhasamanik:seed2  -51.0556    24.1760  300.0000  -2.112

```

## dateJ16:varietyBhasamanik:seed2	-16.7222	24.1760	300.0000	-0.692
## dateS01:varietyBhasamanik:seed2	17.2222	24.1760	300.0000	0.712
## dateS16:varietyBhasamanik:seed2	69.4444	24.1760	300.0000	2.872
## dateA01:varietyNehara:seed2	51.3333	24.1760	300.0000	2.123
## dateA16:varietyNehara:seed2	-44.2222	24.1760	300.0000	-1.829
## dateJ16:varietyNehara:seed2	-58.5556	24.1760	300.0000	-2.422
## dateS01:varietyNehara:seed2	18.8889	24.1760	300.0000	0.781
## dateS16:varietyNehara:seed2	2.9444	24.1760	300.0000	0.122
## dateA01:varietyBhasamanik:seedlocal	-17.9444	24.1760	300.0000	-0.742
## dateA16:varietyBhasamanik:seedlocal	-45.9444	24.1760	300.0000	-1.900
## dateJ16:varietyBhasamanik:seedlocal	-7.1111	24.1760	300.0000	-0.294
## dateS01:varietyBhasamanik:seedlocal	7.8333	24.1760	300.0000	0.324
## dateS16:varietyBhasamanik:seedlocal	107.6667	24.1760	300.0000	4.453
## dateA01:varietyNehara:seedlocal	-22.1667	24.1760	300.0000	-0.917
## dateA16:varietyNehara:seedlocal	-39.9444	24.1760	300.0000	-1.652
## dateJ16:varietyNehara:seedlocal	-24.2222	24.1760	300.0000	-1.002
## dateS01:varietyNehara:seedlocal	28.0556	24.1760	300.0000	1.160
## dateS16:varietyNehara:seedlocal	3.5556	24.1760	300.0000	0.147
## dateA01:varietyBhasamanik:spacing9	-27.3333	24.1760	300.0000	-1.131
## dateA16:varietyBhasamanik:spacing9	-4.5000	24.1760	300.0000	-0.186
## dateJ16:varietyBhasamanik:spacing9	4.3889	24.1760	300.0000	0.182
## dateS01:varietyBhasamanik:spacing9	6.1111	24.1760	300.0000	0.253
## dateS16:varietyBhasamanik:spacing9	-70.2222	24.1760	300.0000	-2.905
## dateA01:varietyNehara:spacing9	-9.0556	24.1760	300.0000	-0.375
## dateA16:varietyNehara:spacing9	-31.8889	24.1760	300.0000	-1.319
## dateJ16:varietyNehara:spacing9	9.8333	24.1760	300.0000	0.407
## dateS01:varietyNehara:spacing9	20.1111	24.1760	300.0000	0.832
## dateS16:varietyNehara:spacing9	-1.8333	24.1760	300.0000	-0.076
## dateA01:varietyBhasamanik:spacing12	-5.1667	24.1760	300.0000	-0.214
## dateA16:varietyBhasamanik:spacing12	9.3333	24.1760	300.0000	0.386
## dateJ16:varietyBhasamanik:spacing12	-7.7222	24.1760	300.0000	-0.319
## dateS01:varietyBhasamanik:spacing12	46.4444	24.1760	300.0000	1.921
## dateS16:varietyBhasamanik:spacing12	-111.8333	24.1760	300.0000	-4.626
## dateA01:varietyNehara:spacing12	3.0556	24.1760	300.0000	0.126
## dateA16:varietyNehara:spacing12	-9.6111	24.1760	300.0000	-0.398
## dateJ16:varietyNehara:spacing12	11.5556	24.1760	300.0000	0.478
## dateS01:varietyNehara:spacing12	5.5000	24.1760	300.0000	0.227
## dateS16:varietyNehara:spacing12	-4.3333	24.1760	300.0000	-0.179
##	Pr(> t)			
## (Intercept)	9.26e-10 ***			
## dateA16	0.202890			
## dateJ16	0.482624			
## dateS01	0.100516			
## dateS16	5.14e-13 ***			
## varietyBhasamanik	0.035516 *			
## varietyNehara	0.000419 ***			
## seed2	0.987047			
## seedlocal	0.135143			
## spacing9	0.261728			
## spacing12	0.539540			
## dateA16:varietyBhasamanik	0.855252			
## dateJ16:varietyBhasamanik	0.416676			
## dateS01:varietyBhasamanik	0.359341			
## dateS16:varietyBhasamanik	0.015646 *			

## dateA16:varietyNehara	0.266419
## dateJ16:varietyNehara	0.275975
## dateS01:varietyNehara	0.252989
## dateS16:varietyNehara	0.007583 **
## dateA16:seed2	0.015633 *
## dateJ16:seed2	0.179865
## dateS01:seed2	0.721953
## dateS16:seed2	0.979850
## dateA16:seedlocal	0.094484 .
## dateJ16:seedlocal	0.956055
## dateS01:seedlocal	0.514501
## dateS16:seedlocal	0.285098
## dateA16:spacing9	0.255284
## dateJ16:spacing9	0.101422
## dateS01:spacing9	0.017579 *
## dateS16:spacing9	0.420545
## dateA16:spacing12	0.211404
## dateJ16:spacing12	0.182851
## dateS01:spacing12	0.000170 ***
## dateS16:spacing12	0.654403
## dateA01:varietyBhasamanik:seed2	0.952397
## dateA16:varietyBhasamanik:seed2	0.035528 *
## dateJ16:varietyBhasamanik:seed2	0.489669
## dateS01:varietyBhasamanik:seed2	0.476791
## dateS16:varietyBhasamanik:seed2	0.004363 **
## dateA01:varietyNehara:seed2	0.034546 *
## dateA16:varietyNehara:seed2	0.068366 .
## dateJ16:varietyNehara:seed2	0.016026 *
## dateS01:varietyNehara:seed2	0.435238
## dateS16:varietyNehara:seed2	0.903145
## dateA01:varietyBhasamanik:seedlocal	0.458522
## dateA16:varietyBhasamanik:seedlocal	0.058337 .
## dateJ16:varietyBhasamanik:seedlocal	0.768855
## dateS01:varietyBhasamanik:seedlocal	0.746154
## dateS16:varietyBhasamanik:seedlocal	1.19e-05 ***
## dateA01:varietyNehara:seedlocal	0.359939
## dateA16:varietyNehara:seedlocal	0.099533 .
## dateJ16:varietyNehara:seedlocal	0.317194
## dateS01:varietyNehara:seedlocal	0.246780
## dateS16:varietyNehara:seedlocal	0.883176
## dateA01:varietyBhasamanik:spacing9	0.259128
## dateA16:varietyBhasamanik:spacing9	0.852465
## dateJ16:varietyBhasamanik:spacing9	0.856067
## dateS01:varietyBhasamanik:spacing9	0.800615
## dateS16:varietyBhasamanik:spacing9	0.003950 **
## dateA01:varietyNehara:spacing9	0.708247
## dateA16:varietyNehara:spacing9	0.188165
## dateJ16:varietyNehara:spacing9	0.684490
## dateS01:varietyNehara:spacing9	0.406149
## dateS16:varietyNehara:spacing9	0.939603
## dateA01:varietyBhasamanik:spacing12	0.830918
## dateA16:varietyBhasamanik:spacing12	0.699728
## dateJ16:varietyBhasamanik:spacing12	0.749633
## dateS01:varietyBhasamanik:spacing12	0.055667 .

```

## dateS16:varietyBhasamanik:spacing12 5.56e-06 ***
## dateA01:varietyNehara:spacing12      0.899510
## dateA16:varietyNehara:spacing12      0.691247
## dateJ16:varietyNehara:spacing12      0.633016
## dateS01:varietyNehara:spacing12      0.820191
## dateS16:varietyNehara:spacing12      0.857870
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

##
## Correlation matrix not shown by default, as p = 75 > 12.
## Use print(x, correlation=TRUE) or
##      vcov(x)          if you need it

```