

# DASC 6510 Project ANOVA Models

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2025-11-27

## 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     4 10.03 81.2276 1.339e-07 ***
## variety                        316064 158032      2     2 20.00 120.1690 7.160e-12 ***
## seed                           65375  32687      2     2 300.00 24.8559 1.027e-10 ***
## spacing                        129705  64852      2     2 300.00 49.3144 < 2.2e-16 ***
## date:variety                  33277   4160      8     8 68.00  3.1630 0.0041865 **
## date:seed                      18579   2322      8     8 300.00  1.7660 0.0832838 .
## date:spacing                   31352   3919      8     8 300.00  2.9800 0.0031555 **
## date:variety:seed              68334   3417     20     20 300.00  2.5981 0.0002758 ***
## date:variety:spacing           52463   2623     20     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
```