

# Using **asremlPlus**, in conjunction with **asreml**, to do a linear mixed model analysis of a wheat experiment using hypothesis tests

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This vignette shows how to use **asremlPlus** (Brien, 2023), in conjunction with **asreml** (Butler et al., 2020), to employ hypothesis tests to select the terms to be included in a mixed model for an experiment that involves spatial variation. It also illustrates diagnostic checking and prediction production and presentation for this experiment. Here, **asremlPlus** and **asreml** are packages for the R Statistical Computing environment (R Core Team, 2023).

It is divided into the following main sections:

1. Set up the maximal model for this experiment
2. Perform a series of hypothesis tests to select a linear mixed model for the data
3. Diagnostic checking using residual plots and variofaces
4. Prediction production and presentation

## 1. Set up the maximal model for this experiment

```
library(knitr)
opts_chunk$set("tidy" = FALSE, comment = NA)
suppressMessages(library(asreml, quietly=TRUE))

## Online License checked out Mon Jun 12 17:41:02 2023

packageVersion("asreml")

## [1] '4.1.0.176'

suppressMessages(library(asremlPlus))
packageVersion("asremlPlus")

## [1] '4.3.53'

suppressMessages(library(qqplotr, quietly=TRUE))
options(width = 100)
```

## Get data available in asremlPlus

The data are from a 1976 spring wheat experiment and are taken from Gilmour et al. (1995). An analysis is presented in the **asreml** manual by Butler et al. (2020, Section 7.6), although they suggest that it is a barley experiment.

```
data(Wheat.dat)
```

## Fit the maximal model

In the following a model is fitted that has the terms that would be included for a balanced lattice. In addition, a term `WithinColPairs` has been included to allow for extraneous variation arising between pairs of adjacent lanes. Also, separable `ar1` residual autocorrelation has been included. This model represents the maximal anticipated model,

```
current.asr <- asreml(yield ~ WithinColPairs + Variety,
  random = ~ Rep/(Row + Column) + units,
  residual = ~ ar1(Row):ar1(Column),
  data=Wheat.dat)
```

Model fitted using the gamma parameterization.

ASReml 4.1.0 Mon Jun 12 17:41:02 2023

	LogLik	Sigma2	DF	wall	cpu
1	-724.121	23034.14	124	17:41:02	0.0
2	-717.415	9206.93	124	17:41:02	0.0 (2 restrained)
3	-694.875	26492.99	124	17:41:02	0.0 (2 restrained)
4	-694.160	33101.80	124	17:41:02	0.0 (1 restrained)
5	-692.002	36912.26	124	17:41:02	0.0 (1 restrained)
6	-691.789	46701.51	124	17:41:02	0.0 (2 restrained)
7	-691.834	46208.51	124	17:41:02	0.0 (1 restrained)
8	-691.775	47698.26	124	17:41:02	0.0
9	-691.771	47041.85	124	17:41:02	0.0

Warning in `asreml(yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Some components changed by more than 1% on the last iteration.`

The warning from `asreml` is probably due to a bound term.

## Initialize a testing sequence by loading the current fit into an `asrtests` object

A label and the information criteria based on the full likelihood (Verbyla, 2019) are included in the `test.summary` stored in the `asrtests` object.

```
current.asrt <- as.asrtests(current.asr, NULL, NULL,
  label = "Maximal model", ICl likelihood = "full")
```

Warning in `infoCriteria.asreml(asreml.obj, ICl likelihood = ic.lik, bound.exclusions = bound.exclusions):`  
Rep

Warning in `asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood not converged`

Calculating denominator DF

## Check for and remove any boundary terms

```
current.asrt <- rmboundary(current.asrt, ICl likelihood = "full")
```

Warning in `infoCriteria.asreml(asreml.obj, ICl likelihood = ic.lik):` The following bound terms were discovered  
Rep

Model fitted using the gamma parameterization.

ASReml 4.1.0 Mon Jun 12 17:41:03 2023

	LogLik	Sigma2	DF	wall	cpu
1	-691.771	47071.42	124	17:41:03	0.0

Warning in `asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Log-likelihood`

not converged

```
summary(current.asrt$asreml.obj)$varcomp
```

	component	std.error	z.ratio	bound	%ch
Rep:Row	4.293282e+03	3.199458e+03	1.3418779	P	0.0
Rep:Column	1.575689e+02	1.480357e+03	0.1064398	P	0.7
units	5.742689e+03	1.652457e+03	3.4752438	P	0.0
Row:Column!R	4.706787e+04	2.515832e+04	1.8708669	P	0.0
Row:Column!Row!cor	7.920301e-01	1.014691e-01	7.8056280	U	0.0
Row:Column!Column!cor	8.799559e-01	7.370402e-02	11.9390486	U	0.0

```
print(current.asrt, which = "testsummary")
```

#### Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

	terms	DF	denDF	p	AIC	BIC	action
1	Maximal model	26	6	NA	1646.129	1742.469	Starting model
2	Rep	1	NA	NA	1646.129	1742.469	Boundary

Rep has been removed because it has been constrained to zero. Following the recommendation of Littell et al. (2006, p. 150), the bound on all variance components is set to unconstrained (U) using `setvariances.asreml` so as to avoid bias in the estimate of the residual variance. Alternatively, one could move Rep to the fixed model.

## Unbind Rep, Row and Column components and reload into an asrtests object

```
current.asr <- setvarianceterms(current.asr$call,  
                                terms = c("Rep", "Rep:Row", "Rep:Column"),  
                                bounds = "U")
```

Model fitted using the gamma parameterization.

ASReml 4.1.0 Mon Jun 12 17:41:03 2023

	LogLik	Sigma2	DF	wall	cpu
1	-724.121	23034.14	124	17:41:03	0.0
2	-717.415	9206.93	124	17:41:03	0.0 (2 restrained)
3	-694.875	26492.99	124	17:41:03	0.0 (2 restrained)
4	-693.974	33129.65	124	17:41:03	0.0 (1 restrained)
5	-692.886	39662.12	124	17:41:03	0.0
6	-691.428	53103.83	124	17:41:03	0.0
7	-691.239	48092.17	124	17:41:03	0.0
8	-691.181	47278.94	124	17:41:03	0.0
9	-691.171	46850.98	124	17:41:03	0.0
10	-691.170	46690.46	124	17:41:03	0.0

Warning in `asreml(fixed = yield ~ WithinColPairs + Variety, random = ~Rep/(Row + : Some components changed by more than 1% on the last iteration.`

Model fitted using the gamma parameterization.

ASReml 4.1.0 Mon Jun 12 17:41:03 2023

	LogLik	Sigma2	DF	wall	cpu
1	-691.170	46641.98	124	17:41:03	0.0
2	-691.170	46637.63	124	17:41:03	0.0

```
current.asrt <- as.asrttests(current.asr, wald.tab = NULL, test.summary = current.asrt$test.summary,
                             IClikelihood = "full", label = "Max model & Unbound components")
```

Calculating denominator DF

```
current.asrt <- rmboundary(current.asrt)
summary(current.asrt$asreml.obj)$varcomp
```

	component	std.error	z.ratio	bound	%ch
Rep	-2458.3485841	1.197491e+03	-2.0529167	U	0.0
Rep:Row	5008.7151485	3.401335e+03	1.4725732	U	0.0
Rep:Column	916.4641197	1.699576e+03	0.5392309	U	0.2
units	5959.0220816	1.609649e+03	3.7020634	P	0.0
Row:Column!R	46637.6303421	2.724392e+04	1.7118545	P	0.0
Row:Column!Row!cor	0.8150590	1.000281e-01	8.1483012	U	0.0
Row:Column!Column!cor	0.8856824	7.492514e-02	11.8208968	U	0.0

```
print(current.asrt, which = "testsummary")
```

#### Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

	terms	DF	denDF	p	AIC	BIC	action
1	Maximal model	26	6	NA	1646.129	1742.469	Starting model
2	Rep	1	NA	NA	1646.129	1742.469	Boundary
3	Max model & Unbound components	26	7	NA	1647.193	1746.544	Starting model

```
print(current.asrt, which = "pseudoanova")
```

#### Pseudo-anova table for fixed terms

Wald tests for fixed effects.

Response: yield

	Df	denDF	F.inc	Pr
(Intercept)	1	1.7	153.500	0.0115
WithinColPairs	1	15.6	2.545	0.1307
Variety	24	76.1	10.110	0.0000

Now the Rep component estimate is negative.

The `test.summary` output has been extended, by supplying the previous `test.summary` to `as.asrttests`, to show that there is a new starting model. The pseudo-anova table shows that Varieties are highly significant ( $p < 0.001$ )

## 2. Perform a series of hypothesis tests to select a linear mixed model for the data

The hypothesis tests in this section are Wald tests for fixed terms, with denominator degrees of freedom calculated using the Kenward-Rogers adjustment (Kenward and Rogers (1997), and Restricted Maximum

Likelihood Ratio Tests (REMLRT) for random terms.

## Check the term for within Column pairs (a post hoc factor)

The information criteria based on the full likelihood (Verbyla, 2019) is also included in the `test.summary` stored in the `asrtests` object.

```
current.asrt <- testranfix(current.asrt, term = "WithinColPairs",  
                           drop.fix.ns=TRUE, IClikelihood = "full")
```

Calculating denominator DF

Warning in `asreml(fixed = yield ~ Variety, random = ~Rep/(Row + Column) + : Some components changed by more than 1% on the last iteration.`

Calculating denominator DF

```
print(current.asrt)
```

#### Summary of the fitted variance parameters

	component	std.error	z.ratio	bound	%ch
Rep	-2385.8697551	1.211207e+03	-1.9698276	U	0.0
Rep:Row	5027.7123253	3.415391e+03	1.4720753	U	0.0
Rep:Column	753.5913536	1.609865e+03	0.4681086	U	0.6
units	5920.3547038	1.611274e+03	3.6743304	P	0.0
Row:Column!R	45870.0971595	2.623601e+04	1.7483638	P	0.0
Row:Column!Row!cor	0.8098786	1.001805e-01	8.0841906	U	0.0
Row:Column!Column!cor	0.8845768	7.510598e-02	11.7777144	U	0.0

#### Pseudo-anova table for fixed terms

Wald tests for fixed effects.

Response: yield

	Df	denDF	F.inc	Pr
(Intercept)	1	1.7	159.20	0.0111
Variety	24	76.8	10.27	0.0000

#### Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

	terms	DF	denDF	p	AIC	BIC	action
1	Maximal model	26	6.0	NA	1646.129	1742.469	Starting model
2	Rep	1	NA	NA	1646.129	1742.469	Boundary
3	Max model & Unbound components	26	7.0	NA	1647.193	1746.544	Starting model
4	WithinColPairs	1	15.6	0.1307	1645.318	1741.658	Dropped

It is clear in the call to `testranfix` that the model is being changed by dropping the `withinColPairs` term, which could also be achieved using `update.asreml`. However, an `asremlPlus` model-changing function operates on an `asrtests` object, that includes an `asreml` object, and, except for `changeTerms.asrtests`,

results in an `asrtests` object that may contain the changed model or the supplied model depending on the results of hypothesis tests or comparisons of information criteria. In addition, the result of the test or comparison will be added to a `test.summary` data.frame stored in the new `asrtests` object and, if the model was changed, the `wald.tab` in the new `asrtests` object will have been updated for the new model.

In this case, as can be seen from the summary of `current.asrt` after the call, the  $p$ -value for the `withinColPairs` was greater than 0.05 and so now the model stored in `current.asrt` does not include `withinColPairs`. The `wald.tab` has been updated for the new model.

## Test the nugget term

The nugget term represents non-spatial variance, such as measurement error. It is fitted using the `asreml` reserved word `units`.

```
current.asrt <- testranfix(current.asrt, "units", positive=TRUE, ICLikelihood = "full")
```

Warning in `asreml(fixed = yield ~ Variety, random = ~Rep + Rep:Row + Rep:Column, : Some components changed by more than 1% on the last iteration.`

## Test Row autocorrelation

We begin testing the autocorrelation by dropping the Row autocorrelation. Because of messages about the instability of the fit, `iterate.asrtests` is used to execute extra iterations of the fitting process.

```
current.asrt <- testresidual(current.asrt, "~ Row:ar1(Column)",
                             label="Row autocorrelation",
                             simplifier=TRUE, ICLikelihood = "full")
```

Warning in `asreml(fixed = yield ~ Variety, random = ~Rep/(Row + Column) + : Log-likelihood not converged`

Warning in `asreml(fixed = yield ~ Variety, random = ~Rep/(Row + Column) + : Some components changed by more than 1% on the last iteration.`

Warning in `asreml(fixed = yield ~ Variety, random = ~Rep/(Row + Column) + : Some components changed by more than 1% on the last iteration.`

```
current.asrt <- iterate(current.asrt)
```

Calculating denominator DF

## Test Column autocorrelation (depends on whether Row autocorrelation retained)

The function `getTestPvalue` is used to get the  $p$ -value for the Row autocorrelation test. If it is significant then the Column autocorrelation is tested by dropping the Column autocorrelation, while retaining the Row autocorrelation. Otherwise the model with just Row autocorrelation, whose fit is returned via `current.asrt` after the test, is compared to one with no autocorrelation.

```
(p <- getTestPvalue(current.asrt, label = "Row autocorrelation"))
```

```
[1] 4.676031e-06
```

```
{ if (p <= 0.05)
  current.asrt <- testresidual(current.asrt, "~ ar1(Row):Column",
                              label="Col autocorrelation",
                              simplifier=TRUE, ICLikelihood = "full")
else
  current.asrt <- testresidual(current.asrt, "~ Row:Column",
                              label="Col autocorrelation",
```

```
simpler=TRUE, ICLikelihood = "full")
}
```

Warning in DFdiff(bound.h1, bound.h0, DF = DF, bound.exclusions = bound.exclusions): There were a total  
 The following bound terms occur in only one of the models compared and so were discounted:  
 Row:Column!Row!cor

## Output the results

```
print(current.asrt, which = "test")
```

#### Sequence of model investigations

(If a row has NA for p but not denDF, DF and denDF relate to fixed and variance parameter numbers)

	terms	DF	denDF	p	AIC	BIC	action
1	Maximal model	26	6.0	NA	1646.129	1742.469	Starting model
2	Rep	1	NA	NA	1646.129	1742.469	Boundary
3	Max model & Unbound components	26	7.0	NA	1647.193	1746.544	Starting model
4	WithinColPairs	1	15.6	0.1307	1645.318	1741.658	Dropped
5	units	1	NA	0.0006	1645.318	1741.658	Retained
6	Row autocorrelation	1	NA	0.0000	1645.318	1741.658	Unswapped
7	Col autocorrelation	2	NA	0.0000	1645.316	1741.656	Unswapped

```
printFormulae(current.asrt$asreml.obj)
```

#### Formulae from asreml object

```
fixed: yield ~ Variety
random: ~ Rep/(Row + Column) + units
residual: ~ ar1(Row):ar1(Column)
```

```
summary(current.asrt$asreml.obj)$varcomp
```

	component	std.error	z.ratio	bound	%ch
Rep	-2384.2946310	1.212190e+03	-1.9669310	U	0.0
Rep:Row	5026.4469057	3.417065e+03	1.4709837	U	0.0
Rep:Column	752.7496589	1.607683e+03	0.4682202	U	0.1
units	5918.7214776	1.611779e+03	3.6721658	P	0.0
Row:Column!R	45854.0579175	2.620961e+04	1.7495130	P	0.0
Row:Column!Row!cor	0.8098355	1.002242e-01	8.0802373	U	0.0
Row:Column!Column!cor	0.8845749	7.513508e-02	11.7731282	U	0.0

The test.summary shows is that the model with Row and without Column autocorrelation failed to converge. The asreml.obj in current.asrt contains the model selected by the selection process, which has been printed using printFormulae.asrttests. It is clear that no changes were made to the variance terms.

### 3. Diagnosing checking using residual plots and variofaces

Get current fitted asreml object and update to include standardized residuals

```
current.asr <- current.asrt$asreml.obj  
current.asr <- update(current.asr, aom=TRUE)
```

Model fitted using the gamma parameterization.

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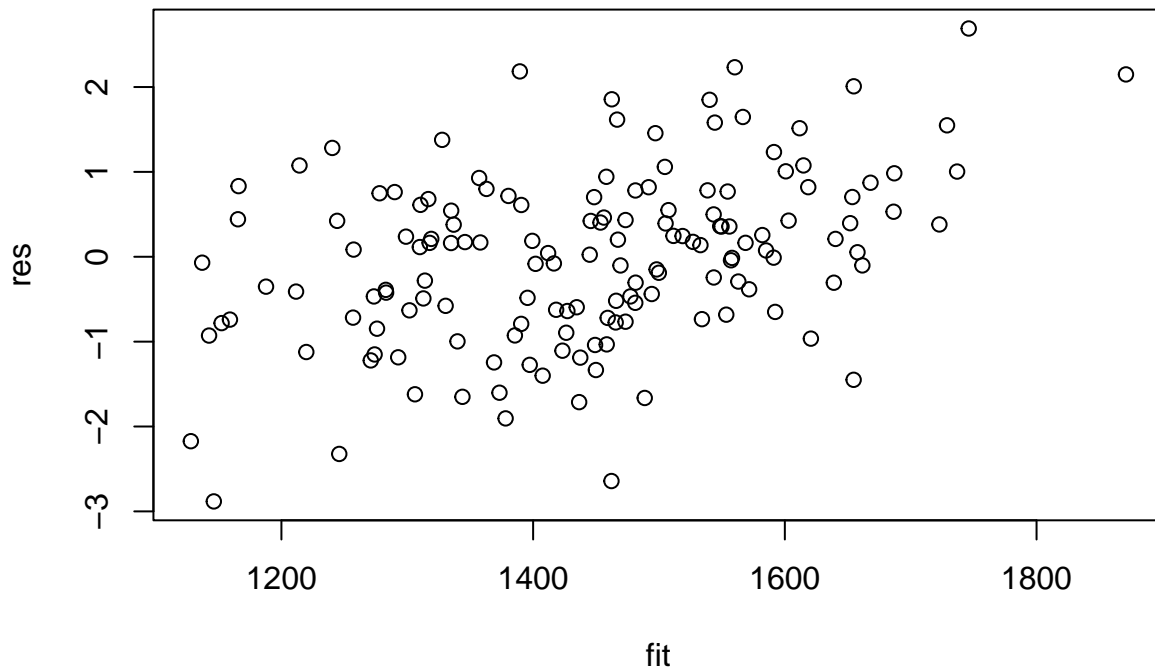
	LogLik	Sigma2	DF	wall	cpu
1	-694.615	45851.09	125	17:41:06	0.0
2	-694.615	45850.89	125	17:41:06	0.0
3	-694.615	45850.39	125	17:41:06	0.0

```
Wheat.dat$res <- residuals(current.asr, type = "stdCond")  
Wheat.dat$fit <- fitted(current.asr)
```

Do diagnostic checking

Do residuals-versus-fitted values plot

```
with(Wheat.dat, plot(fit, res))
```

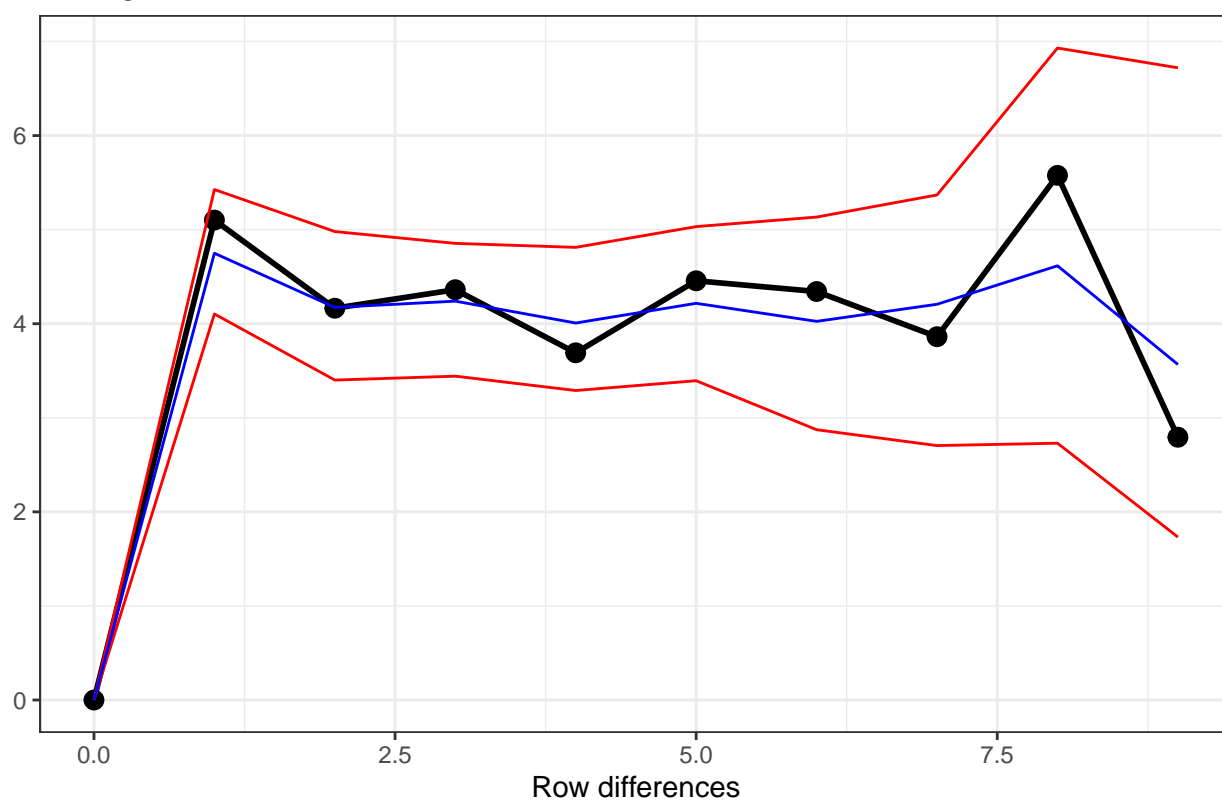


Plot variofaces

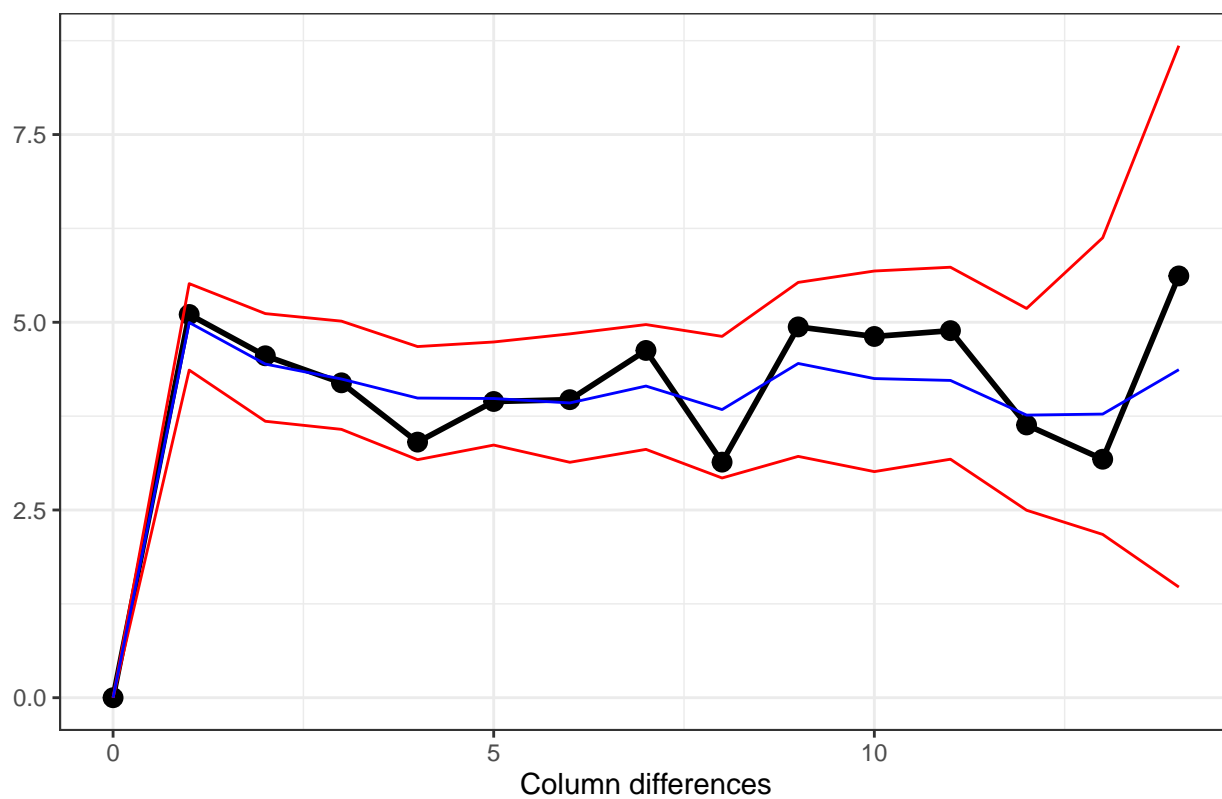
```
variofaces(current.asr, V=NULL, units="addtores",  
            maxiter=50, update = FALSE)
```



Variogram face of Standardized conditional residuals for Row



Variogram face of Standardized conditional residuals for Column



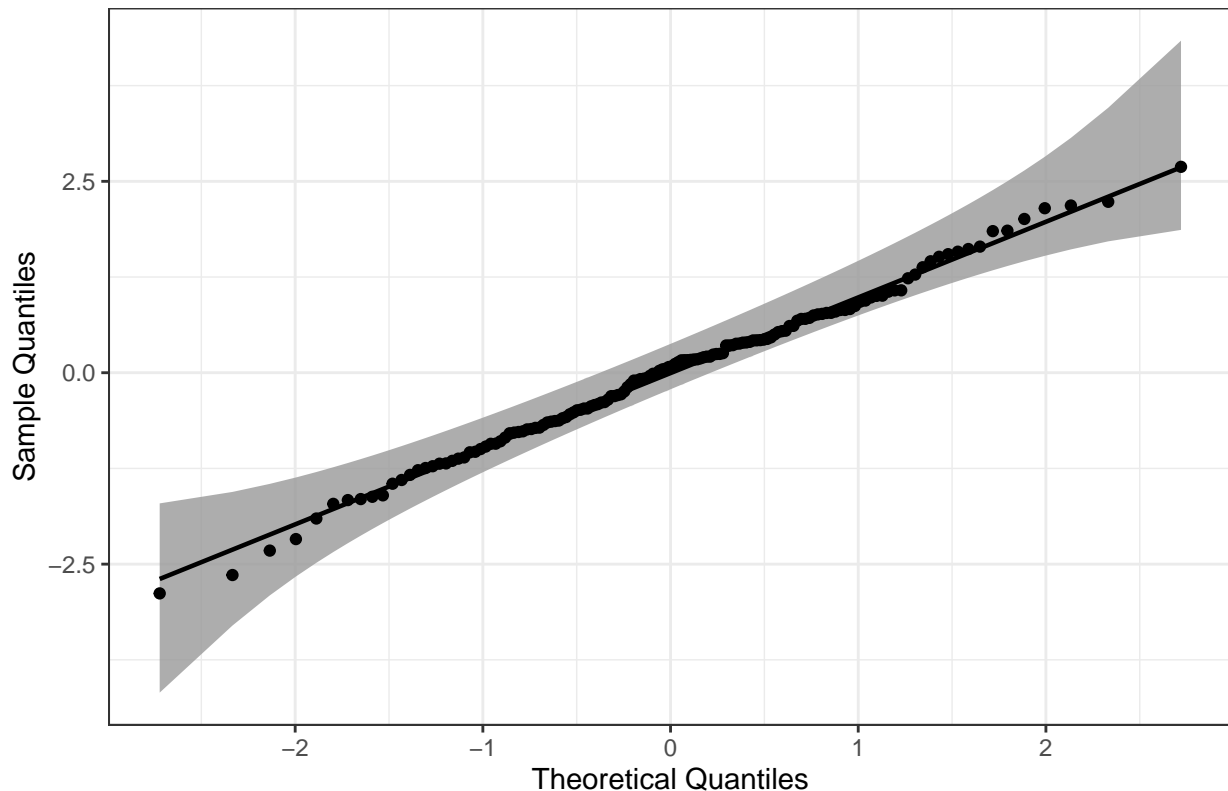
The variofaces are the lag 1 plots of the sample semivariogram with simulated confidence envelopes (Stefanova et al., 2009).

### Plot normal quantile plot

The plot is obtained using the `ggplot` function with extensions available from the `qqplotr` package (Almeida, A., Loy, A. and Hofmann, H., 2023).

```
suppressWarnings(  
  ggplot(data = Wheat.dat, mapping = aes(sample = res)) +  
    stat_qq_band(bandType = "ts") + stat_qq_line() + stat_qq_point() +  
    labs(x = "Theoretical Quantiles", y = "Sample Quantiles",  
         title = "Normal probability plot") +  
    theme(plot.title = element_text(size = 12, face = "bold")) + theme_bw())
```

Normal probability plot



## 4. Prediction production and presentation

Get Variety predictions and all pairwise prediction differences and p-values

```
Var.diffs <- predictPlus(classify = "Variety",  
  asreml.obj=current.asr,  
  error.intervals="halfLeast",  
  wald.tab=current.asrt$wald.tab,  
  sortFactor = "Variety",  
  tables = "predictions")
```

# #### Predictions for yield from Variety

## Notes:

- The predictions are obtained by averaging across the hypertable calculated from model terms constructed solely from factors in the averaging and classify sets.
- Use 'average' to move ignored factors into the averaging set.
- The ignored set: Rep,Row,Column,units
- Variety is included in this prediction
- (Intercept) is included in this prediction
- units is ignored in this prediction

	Variety	predicted.value	standard.error	upper.halfLeastSignificant.limit
1	10	1168.989	120.4766	1228.315
2	1	1242.750	119.8102	1302.076
3	9	1257.137	119.9706	1316.463
4	16	1285.718	119.9398	1345.045
5	14	1293.526	119.9225	1352.853
6	23	1313.653	120.2927	1372.979
7	11	1322.159	120.1962	1381.485
8	7	1374.447	120.2405	1433.773
9	3	1394.070	120.4030	1453.396
10	4	1410.980	120.1053	1470.306
11	12	1444.557	120.6033	1503.883
12	8	1453.397	120.5938	1512.723
13	15	1458.383	120.4344	1517.709
14	5	1473.782	120.4453	1533.108
15	17	1487.828	120.2894	1547.154
16	6	1498.294	120.1187	1557.620
17	21	1517.121	120.2260	1576.447
18	2	1520.466	119.6320	1579.792
19	24	1533.769	120.2993	1593.095
20	18	1541.147	120.3662	1600.474
21	25	1575.795	120.5140	1635.121
22	22	1610.482	120.3279	1669.808
23	13	1610.762	120.4573	1670.088
24	20	1627.971	120.2326	1687.297
25	19	1652.992	120.3433	1712.318
	lower.halfLeastSignificant.limit est.status			
1		1109.663	Estimable	
2		1183.423	Estimable	
3		1197.811	Estimable	
4		1226.392	Estimable	
5		1234.200	Estimable	
6		1254.327	Estimable	
7		1262.833	Estimable	
8		1315.120	Estimable	
9		1334.744	Estimable	
10		1351.653	Estimable	
11		1385.231	Estimable	
12		1394.070	Estimable	

13	1399.057	Estimable
14	1414.456	Estimable
15	1428.501	Estimable
16	1438.968	Estimable
17	1457.795	Estimable
18	1461.140	Estimable
19	1474.443	Estimable
20	1481.821	Estimable
21	1516.468	Estimable
22	1551.156	Estimable
23	1551.436	Estimable
24	1568.645	Estimable
25	1593.666	Estimable

LSD values

minimum LSD = 114.0128

mean LSD = 118.6523

maximum LSD = 123.3578

(sed range / mean sed = 0.0788 )

We have set `error.intervals` to `halfLeast` so that the limits for so that the limits for each `prediction ± (0.5 LSD)` are calculated. When these are plotted overlapping error bars indicate predictions that are not significant, while those that do not overlap are significantly different (Snee, 1981).

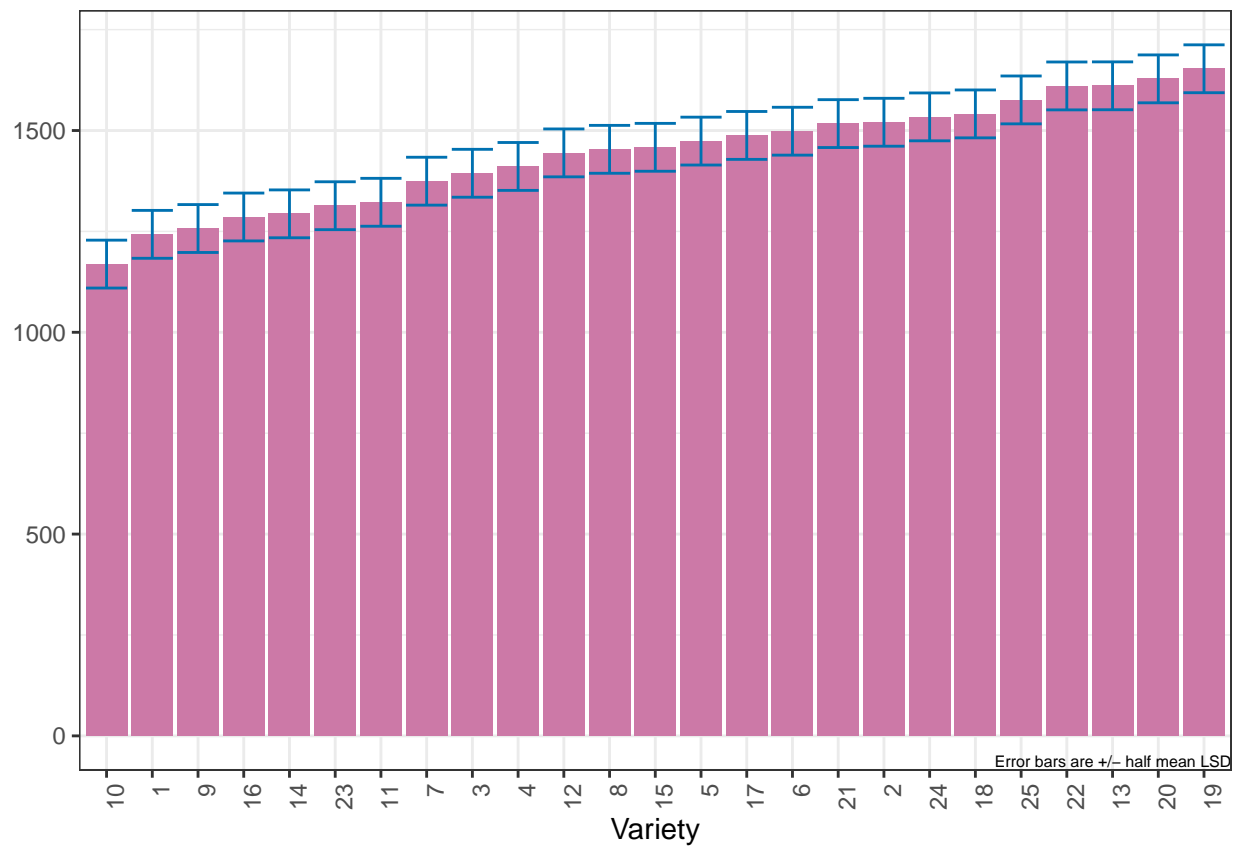
Also set was `sortFactor`, so that the results would be ordered for the values of the predictions for Variety.

The function `predictPlus` returns an `alldiffs` object, a list consisting of the following components:

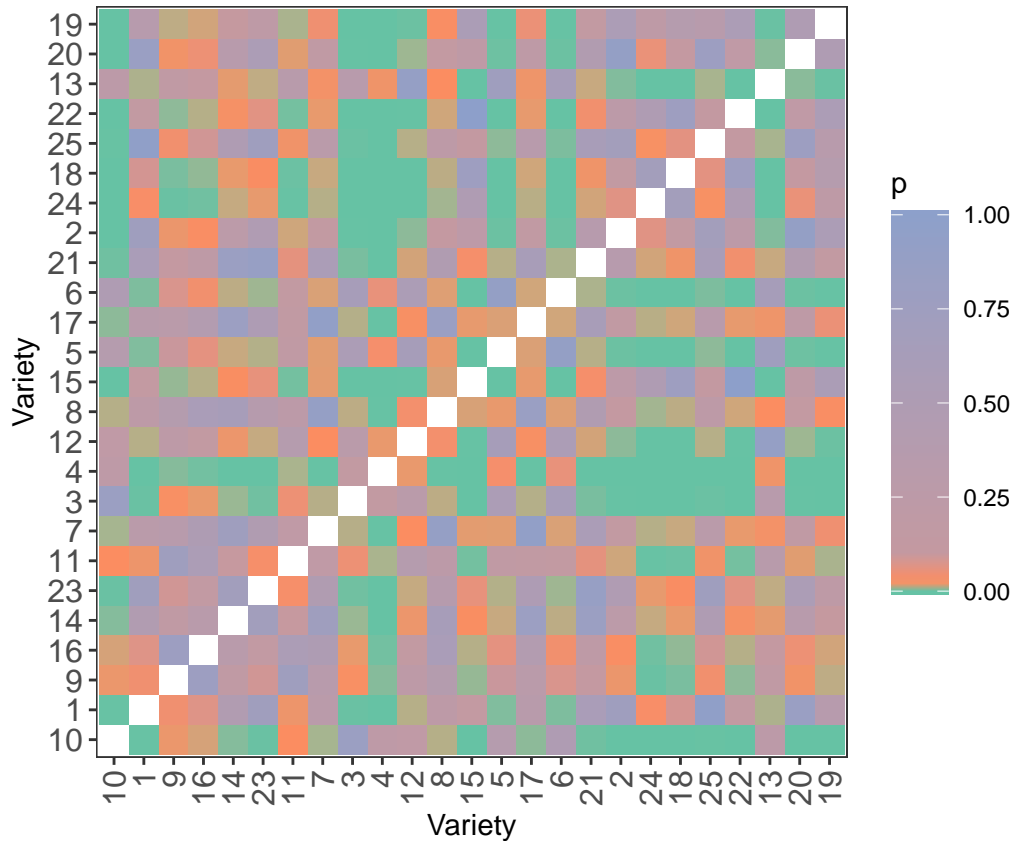
- `predictions`: the predictions, their standard errors and error intervals;
- `vcov`: the variance matrix of the predictions;
- `differences`: all pairwise differences between the predictions,
- `p.differences`: p-values for all pairwise differences between the predictions;
- `sed`: the standard errors of all pairwise differences between the predictions;
- `LSD`: the mean, minimum and maximum LSDs.

**Plot the Variety predictions, with halfLSD intervals, and the p-values**

```
plotPredictions(Var.diffs$predictions,
  classify = "Variety", y = "predicted.value",
  error.intervals = "half")
```



```
plotPvalues(Var.diffs)
```



## References

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