Package 'CANE'

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Type Package

Title Comprehensive Groups of Experiments Analysis for Numerous Environments

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Description Pooled analysis of a series of designed experiments repeated over locations, seasons or years, where treatment-by-environment interaction is of primary interest. One design-specific function call performs environment-wise analysis of variance, formal testing of homogeneity of error variances, an optional variance-stabilising transformation, pooled analysis of variance with the correct error stratum for every effect, and multiple comparison of means. Five classical designs are supported: completely randomised ('PooledCRD()'), randomised block ('PooledRBD()'), Latin square ('PooledLSD()'), split plot ('PooledSPD()') and strip plot ('PooledStPD()'). Homogeneity of error variances is assessed by Bartlett's test computed on the environment-wise error mean squares as in Bartlett (1937) <doi:10.1098/rspa.1937.0109>, and by the median-centred Brown-Forsythe form of Levene's test <doi:10.1080/01621459.1974.10482955>, which is robust to non-normality. When variances are heterogeneous, Aitken's transformation (division of each observation by the square root of the error mean square of its own environment) may be applied, and treatment means are reported on both the transformed and the original scale. For split plot and strip plot designs every effect is tested against its proper error term, and mean separation uses the error mean square and degrees of freedom of the corresponding stratum. The statistical theory is given in Cochran and Cox (1957, ISBN:9780471162032), Gomez and Gomez (1984, ISBN:9780471870928), Dean et 3-319-52250-0> and Ruiz et al. (2024) <doi:10.1007/978-3-031-65575-3>.

Imports stats, utils

Suggests knitr, rmarkdown, testthat (>= 3.0.0), nlme, multcompView

VignetteBuilder knitr

URL https://github.com/Vinayaka11442/CANE

BugReports https://github.com/Vinayaka11442/CANE/issues

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`cane-methods` *Print and Summary Methods for CANE Objects*

Description

Compact display of the objects returned by the pooled analysis functions of the package.

Usage

```
## S3 method for class 'cane_anova'
print(x, digits = 4, ...)

## S3 method for class 'cane_comparison'
print(x, digits = 4, ...)

## S3 method for class 'cane_bartlett'
print(x, digits = 4, ...)

## S3 method for class 'cane_note'
print(x, ...)

## S3 method for class 'cane'
print(x, digits = 4, ...)

## S3 method for class 'cane'
summary(object, digits = 4, ...)
```

Arguments

x, object	An object returned by PooledCRD, PooledRBD, PooledLSD, PooledSPD or PooledStPD.
digits	Number of significant digits used when printing.
...	Further arguments, currently ignored.

Value

print methods return their argument invisibly. summary.cane returns, invisibly, a list with the pooled ANOVA table, the variance-homogeneity tests and the pooled treatment groups.

---

crd_example *Illustrative Completely Randomised Design Series*

Description

A balanced series of completely randomised experiments: four treatments, three environments and five experimental units per treatment within each environment.

Usage

```
crd_example
```

Format

A data frame with 60 rows and 3 variables:

Loc Factor with 3 levels, the environment.

Treatment Factor with 4 levels.

Yield Numeric response.

Details

Simulated from a known additive model with a treatment main effect, an environment main effect, no treatment-by-environment interaction and homogeneous error variances, so that the expected outcome of the analysis is known. Provided for documentation, examples and regression tests.

Examples

```
data(crd_example)
str(crd_example)
```

---

lsd_example *Illustrative Latin Square Design Series*

Description

Three 4 x 4 Latin squares, one per environment, with a different cyclic arrangement in each environment.

Usage

```
lsd_example
```

Format

A data frame with 48 rows and 5 variables:

Location Factor with 3 levels, the environment.

Row Factor with 4 levels, the row of the square.

Column Factor with 4 levels, the column of the square.

Treatment Factor with 4 levels.

Yield Numeric response.

Details

Simulated from a known model containing treatment, environment, row and column effects and no treatment-by-environment interaction. Rows and columns are specific to each environment, which is why the pooled model nests them within environment.

Examples

```
data(lsd_example)
with(lsd_example, table(Treatment, Row, Location))
```

`PooledCRD` *Pooled Analysis of a Series of Completely Randomised Designs*

Description

Performs the classical pooled analysis of variance for a completely randomised design (CRD) repeated over several environments (locations, seasons or years). The function carries out the environment-wise analysis, tests homogeneity of the error variances, optionally applies Aitken's variance-stabilising transformation, fits the pooled model including the treatment-by-environment interaction, and separates treatment means.

Usage

```
PooledCRD(
  data,
  Response,
  Location,
  Treatment,
  alpha = 0.05,
  Mult_Comp_Test = 1,
  transform = c("auto", "always", "never"),
  env_effect = c("fixed", "random")
)
```

Arguments

`data`	A data frame containing the experimental data. Rows with missing values in the variables used are dropped with a warning.
`Response`	Character string naming the numeric response variable.
`Location`	Character string naming the factor that identifies environments (locations, seasons or years).
`Treatment`	Character string naming the treatment factor.
`alpha`	Significance level used for the variance-homogeneity test and for the multiple comparison procedure. Default `0.05`.
`Mult_Comp_Test`	Integer selecting the multiple comparison procedure: `1` = Tukey's honestly significant difference (HSD) test, `2` = Duncan's multiple range test (DMRT), `3` = Fisher's least significant difference (LSD) test. Option `3` makes no adjustment for multiplicity and is intended for a small number of pre-planned comparisons; a warning is issued if it is requested for more than three treatments.
`transform`	One of `"auto"` (default; transform only when the variances are judged heterogeneous at level `alpha`), `"always"` or `"never"`.

`env_effect` One of `"fixed"` (default) or `"random"`. With `"random"` each treatment main effect is tested against its interaction with environment, and in split plot and strip plot designs the interaction of the two treatment factors is tested against the three-way interaction with environment. The pooled comparison of means then uses the same mean square and degrees of freedom as the F-test of the factor compared. With few environments that interaction has few degrees of freedom; if it has fewer than two, the Tukey and Duncan comparisons for that factor are not computed and a warning is issued.

Details

The model fitted within environment j is

$$Y_{ijk} = \mu_j + \tau_{ij} + \epsilon_{ijk}$$

and the pooled model is

$$Y_{ijk} = \mu + \beta_j + \tau_i + (\tau\beta)_{ij} + \epsilon_{ijk},$$

where β_j is the environment effect, τ_i the treatment effect and $(\tau\beta)_{ij}$ their interaction. A completely randomised design has a single error stratum, so every effect is tested against the pooled error mean square when `env_effect = "fixed"`. With `env_effect = "random"` the treatment main effect is tested against the treatment-by-environment interaction, which is the appropriate denominator when the environments are regarded as a random sample from a target population.

Homogeneity of error variances is tested by Bartlett's statistic computed on the environment-wise error mean squares, each carrying its own error degrees of freedom. Because Bartlett's test is sensitive to non-normality, the median-centred (Brown-Forsythe) form of Levene's test and environment-wise Shapiro-Wilk tests are reported alongside it. Levene's test is computed on the environment-wise residuals; because the residuals of environment j carry only its error degrees of freedom ν_j (with two replications they occur in exact plus-minus pairs), its denominator degrees of freedom are $\sum_j \nu_j$ rather than $N - l$. The `transform` argument lets the user override the automatic decision.

Value

An object of class `"cane"`, a list with components

`Design` Name of the design analysed.

`Individual_ANOVA` List of environment-wise ANOVA tables.

`Location_wise` Environment-wise multiple comparisons, each computed from the error mean square of that environment.

`Bartlett_Test` Bartlett's test on the error mean squares. For split plot and strip plot designs, element `other_strata` gives the same test for the main plot or strip error strata.

`Levene_Test` Median-centred Levene (Brown-Forsythe) test.

`Normality_Test` Environment-wise Shapiro-Wilk tests.

`Transformation` Whether Aitken's transformation was applied, why, the environment-wise error mean squares and the ratio of the largest to the smallest.

`Pooled_ANOVA` Pooled ANOVA table, including the error term used as the denominator of each F-test.

`Treatments_Comparison` Pooled treatment means, groups and all pairwise differences. When a transformation was applied, means are given on the transformed scale (on which the test was performed) and the arithmetic means on the original scale are reported alongside.

`GEI_Note` Advice issued when any interaction of a treatment factor with environment is significant, naming the terms concerned.

`Environment_Key` Mapping of environment levels to their error mean square and error degrees of freedom.

`Settings` Arguments and software versions used.

References

Aitken, A. C. (1935). On least squares and linear combination of observations. *Proceedings of the Royal Society of Edinburgh*, 55, 42–48. doi:10.1017/S0370164600014346

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London A*, 160, 268–282. doi:10.1098/rspa.1937.0109

Cochran, W. G. and Cox, G. M. (1957). *Experimental Designs*, 2nd ed. John Wiley and Sons, New York.

Dean, A., Voss, D. and Draguljic, D. (2017). *Design and Analysis of Experiments*, 2nd ed. Springer, Cham. doi:10.1007/9783319522500

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd ed. John Wiley and Sons, New York.

See Also

`PooledRBD`, `PooledLSD`, `PooledSPD`, `PooledStPD`

Examples

```
data(crd_example)
out <- PooledCRD(crd_example, Response = "Yield", Location = "Loc",
                 Treatment = "Treatment", alpha = 0.05, Mult_Comp_Test = 1)
out
out$Pooled_ANOVA
```

`PooledLSD` *Pooled Analysis of a Series of Latin Square Designs*

Description

Performs the classical pooled analysis of variance for a Latin square design repeated over several environments, with rows and columns correctly nested within environment.

Usage

```
PooledLSD(
  data,
  Response,
  Location,
  Treatment,
  Row,
  Column,
  alpha = 0.05,
  Mult_Comp_Test = 1,
  transform = c("auto", "always", "never"),
  env_effect = c("fixed", "random")
)
```

Arguments

`data`	A data frame containing the experimental data. Rows with missing values in the variables used are dropped with a warning.
`Response`	Character string naming the numeric response variable.
`Location`	Character string naming the factor that identifies environments (locations, seasons or years).
`Treatment`	Character string naming the treatment factor.
`Row`	Character string naming the row factor of the square.
`Column`	Character string naming the column factor of the square.
`alpha`	Significance level used for the variance-homogeneity test and for the multiple comparison procedure. Default `0.05`.
`Mult_Comp_Test`	Integer selecting the multiple comparison procedure: `1` = Tukey's honestly significant difference (HSD) test, `2` = Duncan's multiple range test (DMRT), `3` = Fisher's least significant difference (LSD) test. Option `3` makes no adjustment for multiplicity and is intended for a small number of pre-planned comparisons; a warning is issued if it is requested for more than three treatments.
`transform`	One of `"auto"` (default; transform only when the variances are judged heterogeneous at level `alpha`), `"always"` or `"never"`.
`env_effect`	One of `"fixed"` (default) or `"random"`. With `"random"` each treatment main effect is tested against its interaction with environment, and in split plot and strip plot designs the interaction of the two treatment factors is tested against the three-way interaction with environment. The pooled comparison of means then uses the same mean square and degrees of freedom as the F-test of the factor compared. With few environments that interaction has few degrees of freedom; if it has fewer than two, the Tukey and Duncan comparisons for that factor are not computed and a warning is issued.

Details

The model fitted within environment j is

$$Y_{ijkm} = \mu_j + \rho_{jk} + \gamma_{jm} + \tau_{ij} + \epsilon_{ijkm}$$

with ρ_{jk} the row effect and γ_{jm} the column effect. In the pooled model rows and columns are **nested within environment**, because each environment carries its own Latin square: row 1 at one site is a different strip of land from row 1 at another. Nesting gives $l(t-1)$ degrees of freedom each for rows and columns. Treating rows and columns as crossed with environment instead would absorb $(l-1)(t-1)$ genuine blocking degrees of freedom into the error term and bias every F-test.

Value

An object of class `"cane"`, a list with components

`Design` Name of the design analysed.

`Individual_ANOVA` List of environment-wise ANOVA tables.

`Location_wise` Environment-wise multiple comparisons, each computed from the error mean square of that environment.

`Bartlett_Test` Bartlett's test on the error mean squares. For split plot and strip plot designs, element `other_strata` gives the same test for the main plot or strip error strata.

`Levene_Test` Median-centred Levene (Brown-Forsythe) test.

`Normality_Test` Environment-wise Shapiro-Wilk tests.

`Transformation` Whether Aitken's transformation was applied, why, the environment-wise error mean squares and the ratio of the largest to the smallest.

`Pooled_ANOVA` Pooled ANOVA table, including the error term used as the denominator of each F-test.

`Treatments_Comparison` Pooled treatment means, groups and all pairwise differences. When a transformation was applied, means are given on the transformed scale (on which the test was performed) and the arithmetic means on the original scale are reported alongside.

`GEI_Note` Advice issued when any interaction of a treatment factor with environment is significant, naming the terms concerned.

`Environment_Key` Mapping of environment levels to their error mean square and error degrees of freedom.

`Settings` Arguments and software versions used.

References

Aitken, A. C. (1935). On least squares and linear combination of observations. *Proceedings of the Royal Society of Edinburgh*, 55, 42–48. doi:10.1017/S0370164600014346

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London A*, 160, 268–282. doi:10.1098/rspa.1937.0109

Cochran, W. G. and Cox, G. M. (1957). *Experimental Designs*, 2nd ed. John Wiley and Sons, New York.

Dean, A., Voss, D. and Draguljic, D. (2017). *Design and Analysis of Experiments*, 2nd ed. Springer, Cham. doi:10.1007/9783319522500

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd ed. John Wiley and Sons, New York.

See Also

PooledCRD, PooledRBD, PooledSPD, PooledStPD

Examples

```
data(lsd_example)
out <- PooledLSD(lsd_example, Response = "Yield", Location = "Location",
                 Treatment = "Treatment", Row = "Row", Column = "Column",
                 alpha = 0.05, Mult_Comp_Test = 1)
out
out$Pooled_ANOVA
```

PooledRBD *Pooled Analysis of a Series of Randomised Block Designs*

Description

Performs the classical pooled analysis of variance for a randomised block design (RBD) repeated over several environments. This is the workhorse analysis of multi-environment variety and agronomy trials.

Usage

```
PooledRBD(
  data,
  Response,
  Location,
  Treatment,
  Replication,
  alpha = 0.05,
  Mult_Comp_Test = 1,
  transform = c("auto", "always", "never"),
  env_effect = c("fixed", "random")
)
```

Arguments

data	A data frame containing the experimental data. Rows with missing values in the variables used are dropped with a warning.
Response	Character string naming the numeric response variable.
Location	Character string naming the factor that identifies environments (locations, seasons or years).
Treatment	Character string naming the treatment factor.
Replication	Character string naming the replication (block) factor.

`alpha` Significance level used for the variance-homogeneity test and for the multiple comparison procedure. Default `0.05`.

`Mult_Comp_Test` Integer selecting the multiple comparison procedure: `1` = Tukey's honestly significant difference (HSD) test, `2` = Duncan's multiple range test (DMRT), `3` = Fisher's least significant difference (LSD) test. Option `3` makes no adjustment for multiplicity and is intended for a small number of pre-planned comparisons; a warning is issued if it is requested for more than three treatments.

`transform` One of `"auto"` (default; transform only when the variances are judged heterogeneous at level `alpha`), `"always"` or `"never"`.

`env_effect` One of `"fixed"` (default) or `"random"`. With `"random"` each treatment main effect is tested against its interaction with environment, and in split plot and strip plot designs the interaction of the two treatment factors is tested against the three-way interaction with environment. The pooled comparison of means then uses the same mean square and degrees of freedom as the F-test of the factor compared. With few environments that interaction has few degrees of freedom; if it has fewer than two, the Tukey and Duncan comparisons for that factor are not computed and a warning is issued.

Details

The model fitted within environment j is

$$Y_{ijk} = \mu_j + \rho_{jk} + \tau_{ij} + \epsilon_{ijk}$$

with ρ_{jk} the effect of replication k in environment j. The pooled model is

$$Y_{ijk} = \mu + \beta_j + \rho_{k(j)} + \tau_i + (\tau\beta)_{ij} + \epsilon_{ijk},$$

replications being nested within environments, which gives $l(r-1)$ degrees of freedom for replication rather than $r-1$.

Following the standard treatment of a series of block experiments, the environment main effect is tested against the replication-within-environment mean square, because replications are the units within which environments are compared. Treatment and the treatment-by-environment interaction are tested against the pooled error when `env_effect = "fixed"`. When `env_effect = "random"` the treatment main effect is tested against the treatment-by-environment interaction instead.

Value

An object of class `"cane"`, a list with components

`Design` Name of the design analysed.

`Individual_ANOVA` List of environment-wise ANOVA tables.

`Location_wise` Environment-wise multiple comparisons, each computed from the error mean square of that environment.

`Bartlett_Test` Bartlett's test on the error mean squares. For split plot and strip plot designs, element `other_strata` gives the same test for the main plot or strip error strata.

`Levene_Test` Median-centred Levene (Brown-Forsythe) test.

`Normality_Test` Environment-wise Shapiro-Wilk tests.

`Transformation` Whether Aitken's transformation was applied, why, the environment-wise error mean squares and the ratio of the largest to the smallest.

`Pooled_ANOVA` Pooled ANOVA table, including the error term used as the denominator of each F-test.

`Treatments_Comparison` Pooled treatment means, groups and all pairwise differences. When a transformation was applied, means are given on the transformed scale (on which the test was performed) and the arithmetic means on the original scale are reported alongside.

`GEI_Note` Advice issued when any interaction of a treatment factor with environment is significant, naming the terms concerned.

`Environment_Key` Mapping of environment levels to their error mean square and error degrees of freedom.

`Settings` Arguments and software versions used.

References

Aitken, A. C. (1935). On least squares and linear combination of observations. *Proceedings of the Royal Society of Edinburgh*, 55, 42–48. doi:10.1017/S0370164600014346

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London A*, 160, 268–282. doi:10.1098/rspa.1937.0109

Cochran, W. G. and Cox, G. M. (1957). *Experimental Designs*, 2nd ed. John Wiley and Sons, New York.

Dean, A., Voss, D. and Draguljic, D. (2017). *Design and Analysis of Experiments*, 2nd ed. Springer, Cham. doi:10.1007/9783319522500

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd ed. John Wiley and Sons, New York.

See Also

`PooledCRD`, `PooledLSD`, `PooledSPD`, `PooledStPD`

Examples

```
data(sugarcane)
out <- PooledRBD(sugarcane, Response = "ccsy", Location = "env",
                 Treatment = "gen", Replication = "rep",
                 alpha = 0.05, Mult_Comp_Test = 1)
out
out$Pooled_ANOVA
head(out$Treatments_Comparison$groups)
```

PooledSPD *Pooled Analysis of a Series of Split Plot Designs*

Description

Performs the classical pooled analysis of variance for a split plot design (SPD) repeated over several environments, with every effect tested against its proper error term.

Usage

```
PooledSPD(
  data,
  Response,
  Location,
  Replication,
  MainPlot,
  SubPlot,
  alpha = 0.05,
  Mult_Comp_Test = 1,
  transform = c("auto", "always", "never"),
  env_effect = c("fixed", "random")
)
```

Arguments

`data`	A data frame containing the experimental data. Rows with missing values in the variables used are dropped with a warning.
`Response`	Character string naming the numeric response variable.
`Location`	Character string naming the factor that identifies environments (locations, seasons or years).
`Replication`	Character string naming the replication factor.
`MainPlot`	Character string naming the main plot (whole plot) factor, that is the factor requiring the larger experimental units.
`SubPlot`	Character string naming the subplot factor.
`alpha`	Significance level used for the variance-homogeneity test and for the multiple comparison procedure. Default `0.05`.
`Mult_Comp_Test`	Integer selecting the multiple comparison procedure: `1` = Tukey's honestly significant difference (HSD) test, `2` = Duncan's multiple range test (DMRT), `3` = Fisher's least significant difference (LSD) test. Option `3` makes no adjustment for multiplicity and is intended for a small number of pre-planned comparisons; a warning is issued if it is requested for more than three treatments.
`transform`	One of `"auto"` (default; transform only when the variances are judged heterogeneous at level `alpha`), `"always"` or `"never"`.

`env_effect` One of `"fixed"` (default) or `"random"`. With `"random"` each treatment main effect is tested against its interaction with environment, and in split plot and strip plot designs the interaction of the two treatment factors is tested against the three-way interaction with environment. The pooled comparison of means then uses the same mean square and degrees of freedom as the F-test of the factor compared. With few environments that interaction has few degrees of freedom; if it has fewer than two, the Tukey and Duncan comparisons for that factor are not computed and a warning is issued.

Details

A split plot design has two error strata. Main plot effects belong to the main plot stratum and must be tested against the main plot error, $Environment \times Replication \times MainPlot$; subplot effects and all interactions involving the subplot factor belong to the subplot stratum and are tested against the subplot (residual) error. Testing a main plot effect against the subplot error, as happens if a single-stratum model is fitted and its residual mean square is used for everything, gives an F-ratio with the wrong denominator and the wrong denominator degrees of freedom.

The pooled partition implemented here is

$$Environment,\ Rep(Env),\ A,\ A \times Env,\ \text{main plot error},$$

$$B,\ B \times Env,\ A \times B,\ A \times B \times Env,\ \text{subplot error},$$

where A is the main plot factor and B the subplot factor. With l environments, r replications, a main plot levels and b subplot levels the main plot error carries $l(r-1)(a-1)$ degrees of freedom and the subplot error $la(r-1)(b-1)$.

Mean separation is carried out in the stratum appropriate to each factor: main plot means are compared using the main plot error mean square and its degrees of freedom, subplot means using the subplot error. The stratum used is recorded in the `parameters` component of each comparison.

Homogeneity of error variances is assessed for both strata. The main Bartlett test, and the Aitken transformation when it is applied, use the subplot error mean square of each environment; the main plot error mean squares are tested separately and reported in `Bartlett_Test$other_strata`, with a note in the transformation report if they are heterogeneous.

At least two replications per environment are needed for a main plot error to exist, and three or more are strongly advised: with $r = 2$ and $a = 2$ the main plot error has only l degrees of freedom and the main plot test has almost no power.

Value

An object of class `"cane"`. The structure is as described in `PooledCRD`, except that `Location_wise` and `Treatments_Comparison` are each a list with components `MainPlot` and `SubPlot`, computed from the main plot and subplot error strata respectively.

References

Aitken, A. C. (1935). On least squares and linear combination of observations. *Proceedings of the Royal Society of Edinburgh*, 55, 42–48. doi:10.1017/S0370164600014346

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London A*, 160, 268–282. doi:10.1098/rspa.1937.0109

Cochran, W. G. and Cox, G. M. (1957). *Experimental Designs*, 2nd ed. John Wiley and Sons, New York.

Dean, A., Voss, D. and Draguljic, D. (2017). *Design and Analysis of Experiments*, 2nd ed. Springer, Cham. doi:10.1007/9783319522500

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd ed. John Wiley and Sons, New York.

See Also

PooledCRD, PooledRBD, PooledLSD, PooledStPD

Examples

```
data(spd_example)
out <- PooledSPD(spd_example, Response = "Yield", Location = "Location",
                 Replication = "Replication", MainPlot = "MainPlot",
                 SubPlot = "SubPlot", alpha = 0.05, Mult_Comp_Test = 1)
out
out$Pooled_ANOVA
out$Treatments_Comparison$MainPlot$parameters
```

PooledStPD *Pooled Analysis of a Series of Strip Plot Designs*

Description

Performs the classical pooled analysis of variance for a strip plot (split block) design repeated over several environments, with three error strata handled explicitly.

Usage

```
PooledStPD(
  data,
  Response,
  Location,
  Replication,
  RowFactor,
  ColumnFactor,
  alpha = 0.05,
  Mult_Comp_Test = 1,
  transform = c("auto", "always", "never"),
  env_effect = c("fixed", "random")
)
```

Arguments

`data`	A data frame containing the experimental data. Rows with missing values in the variables used are dropped with a warning.
`Response`	Character string naming the numeric response variable.
`Location`	Character string naming the factor that identifies environments (locations, seasons or years).
`Replication`	Character string naming the replication factor.
`RowFactor`	Character string naming the factor applied in horizontal strips.
`ColumnFactor`	Character string naming the factor applied in vertical strips.
`alpha`	Significance level used for the variance-homogeneity test and for the multiple comparison procedure. Default `0.05`.
`Mult_Comp_Test`	Integer selecting the multiple comparison procedure: `1` = Tukey's honestly significant difference (HSD) test, `2` = Duncan's multiple range test (DMRT), `3` = Fisher's least significant difference (LSD) test. Option `3` makes no adjustment for multiplicity and is intended for a small number of pre-planned comparisons; a warning is issued if it is requested for more than three treatments.
`transform`	One of `"auto"` (default; transform only when the variances are judged heterogeneous at level `alpha`), `"always"` or `"never"`.
`env_effect`	One of `"fixed"` (default) or `"random"`. With `"random"` each treatment main effect is tested against its interaction with environment, and in split plot and strip plot designs the interaction of the two treatment factors is tested against the three-way interaction with environment. The pooled comparison of means then uses the same mean square and degrees of freedom as the F-test of the factor compared. With few environments that interaction has few degrees of freedom; if it has fewer than two, the Tukey and Duncan comparisons for that factor are not computed and a warning is issued.

Details

In a strip plot design the two factors are applied in perpendicular strips, which creates **three** error terms: a row strip error, a column strip error and an intersection error. The row factor must be tested against the row strip error $Environment \times Replication \times Row$, the column factor against the column strip error $Environment \times Replication \times Column$, and their interaction against the intersection (residual) error. The interaction is therefore estimated with the greatest precision, which is the characteristic merit of the design.

With l environments, r replications, a row levels and b column levels the three errors carry $l(r-1)(a-1)$, $l(r-1)(b-1)$ and $l(r-1)(a-1)(b-1)$ degrees of freedom.

Homogeneity of error variances is assessed for all three strata: the main Bartlett test uses the intersection error mean squares, and the row strip and column strip error mean squares are tested separately and reported in `Bartlett_Test$other_strata`.

Aitken's transformation, when applied, divides each observation by the square root of the *intersection error mean square* of its own environment, matching the definition used by the other functions in the package. The lookup is by environment label, so it is unaffected by the row order of `data`.

Value

An object of class "cane". The structure is as described in PooledCRD, except that Location_wise and Treatments_Comparison are each a list with components RowFactor, ColumnFactor and Interaction, computed from the row strip, column strip and intersection error strata respectively.

References

Aitken, A. C. (1935). On least squares and linear combination of observations. *Proceedings of the Royal Society of Edinburgh*, 55, 42–48. doi:10.1017/S0370164600014346

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London A*, 160, 268–282. doi:10.1098/rspa.1937.0109

Cochran, W. G. and Cox, G. M. (1957). *Experimental Designs*, 2nd ed. John Wiley and Sons, New York.

Dean, A., Voss, D. and Draguljic, D. (2017). *Design and Analysis of Experiments*, 2nd ed. Springer, Cham. doi:10.1007/9783319522500

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd ed. John Wiley and Sons, New York.

See Also

PooledCRD, PooledRBD, PooledLSD, PooledSPD

Examples

```
data(stpd_example)
out <- PooledStPD(stpd_example, Response = "Yield", Location = "Location",
                  Replication = "Replication", RowFactor = "RowFactor",
                  ColumnFactor = "ColumnFactor", alpha = 0.05,
                  Mult_Comp_Test = 1)
out
out$Pooled_ANOVA
```

---

spd_example *Illustrative Split Plot Design Series*

Description

A balanced series of split plot experiments: two environments, four replications, two main plot levels and three subplot levels.

Usage

```
spd_example
```

Format

A data frame with 48 rows and 5 variables:

Location Factor with 2 levels, the environment.

Replication Factor with 4 levels.

MainPlot Factor with 2 levels, the main plot (whole plot) factor.

SubPlot Factor with 3 levels, the subplot factor.

Yield Numeric response.

Details

Simulated from a known model with a genuine main plot error component in addition to the subplot error, so that the two error strata of the design are both identifiable. Four replications are used so that the main plot error has adequate degrees of freedom.

Examples

```
data(spd_example)
with(spd_example, table(MainPlot, SubPlot, Location))
```

---

stpd_example *Illustrative Strip Plot Design Series*

Description

A balanced series of strip plot (split block) experiments: two environments, four replications, two row strip levels and three column strip levels.

Usage

```
stpd_example
```

Format

A data frame with 48 rows and 5 variables:

Location Factor with 2 levels, the environment.

Replication Factor with 4 levels.

RowFactor Factor with 2 levels, applied in horizontal strips.

ColumnFactor Factor with 3 levels, applied in vertical strips.

Yield Numeric response.

Details

Simulated from a known model containing separate row strip, column strip and intersection error components, so that all three error strata of the design are identifiable.

Examples

```
data(stpd_example)
with(stpd_example, table(RowFactor, ColumnFactor, Location))
```

`sugarcane` *Sugarcane Multi-Environment Trial (Commercial Cane Sugar Yield)*

Description

Commercial cane sugar yield of 18 sugarcane (*Saccharum* spp. hybrids) genotypes evaluated in a randomised block design at two locations in peninsular India over three crop cycles, giving six environments.

Usage

```
sugarcane
```

Format

A data frame with 216 rows and 6 variables:

env Factor with 6 levels, the environment (location-by-crop-cycle).

loc Factor with 2 levels, `SGA` and `TCSM`.

crop Factor with 3 levels, `IP`, `IIP` and `R`.

rep Factor with 2 levels, the replication (block) within environment.

gen Factor with 18 levels, the genotype.

ccsy Numeric, commercial cane sugar yield in t/ha.

Details

The trials were conducted by the ICAR-Sugarcane Breeding Institute at Sakthi Sugars, Sivaganga (SGA) and Tiruttani Cooperative Sugar Mills, Thiruvalangadu (TCSM), both in Tamil Nadu, India. The three crop cycles are plant I (IP), plant II (IIP) and ratoon (R). The six environments are the location-by-cycle combinations, labelled `SGA-IP`, `SGA-IIP`, `SGA-R`, `TCSM-IP`, `TCSM-IIP` and `TCSM-R`.

Two replications are distributed. A third column of values present in an earlier working version of these data was found, on audit, to be identically the arithmetic mean of the two observed replicates in the `SGA-R`, `TCSM-IIP` and `TCSM-R` trials, for every one of the 18 genotypes. Such a value is a derived quantity, not an independently randomised experimental unit: including it leaves the error sum of squares of those environments unchanged while doubling the error degrees of freedom, which halves the error mean square; because the genotype means are unchanged, the genotype sum of squares is at the same time multiplied by three halves, so the genotype F-ratio is inflated by exactly three. Only the two genuine replicates are therefore included, giving a fully balanced series of six two-replicate randomised block experiments.

Source

ICAR-Sugarcane Breeding Institute, Coimbatore, Tamil Nadu, India. Institute Plan Project P1-15/4-1(v).

Examples

```
data(sugarcane)
str(sugarcane)
with(sugarcane, table(env, rep))
round(tapply(sugarcane$ccsy, sugarcane$env, mean), 3)
```

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