The `germinationmetrics` Package: A Brief Introduction

Aravind, J., Vimala Devi, S., Radhamani, J., Jacob, S. R., and Kalyani Srinivasan

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ICAR-National Bureau of Plant Genetic Resources, New Delhi.

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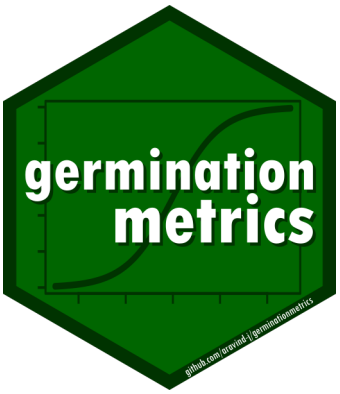
Overview



The package `germinationmetrics` is a collection of functions which implements various methods for describing the time-course of germination in terms of single-value germination indices as well as fitted curves.

The goal of this vignette is to introduce the users to these functions and get started in describing sequentially recorded germination count data. This document assumes a basic knowledge of `R` programming language.

Installation

The package can be installed using the following functions:

```
# Install from CRAN
install.packages('germinationmetrics', dependencies=TRUE)

# Install development version from Github
devtools::install_github("aravind-j/germinationmetrics")
```

Then the package can be loaded using the function

```
library(germinationmetrics)
```

Version History

The current version of the package is 0.1.3. The previous versions are as follows.

Table 1. Version history of `germinationmetrics` `R` package.

Version	Date
0.1.0	2018-04-17
0.1.1	2018-07-26
0.1.1.1	2018-10-16
0.1.2	2018-10-31

To know detailed history of changes use `news(package='germinationmetrics')`.

Germination count data

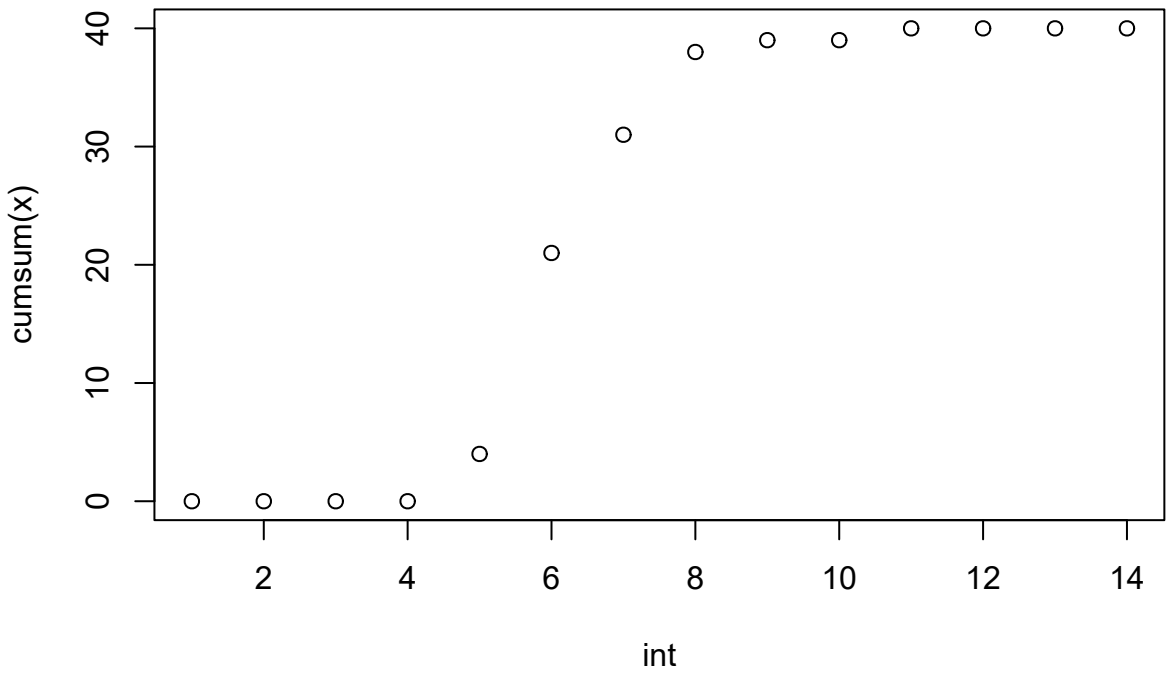
Typically in a germination test, the germination count data of a fixed number of seeds is recorded at regular intervals for a definite period of time or until all the seeds have germinated. These germination count data can be either partial or cumulative (Table 2).

Table 2 : A typical germination count data.

intervals	counts	cumulative.counts
1	0	0
2	0	0
3	0	0
4	0	0
5	4	4
6	17	21
7	10	31
8	7	38
9	1	39
10	0	39
11	1	40
12	0	40
13	0	40
14	0	40

The time-course of germination can be plotted as follows:

```
data <- data.frame(intervals = 1:14,
                   counts = c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0))

# Partial germination counts
x <- data$counts
# Cumulative germination counts
y <- cumsum(x)
# Time intervals of observations
int <- data$intervals

plot(int, cumsum(x))
```



Single-value germination indices

The details about the single-value germination indices implemented in `germinationmetrics` are described in Table 3.

Table 3 : Single-value germination indices implemented in `germinationmetrics`.

Germination index	function	Details	Unit	Measures	Reference
Germination percentage or Germinability (GP)	`GermPercent`	It is computed as follows: $$GP = \frac{N_g}{N_t} \times 100$$ Where, N_g is the number of germinated seeds and N_t is the total number of seeds.	Percentage (%)	Germination capacity	ISTA (2015)
Time for the first germination or Germination time lag (t_0)	`FirstGermTime`	It is the time for first germination to occur (e.g. First day of germination)	time	Germination time	Edwards (1932); Czabator (1962); Goloff and Bazzaz (1975); Labouriau (1983a); Ranal (1999); Quintanilla et al. (2000)
Time for the last germination (t_g)	`LastGermTime`	It is the time for last germination to occur (e.g. Last day of germination)	time	Germination time	Edwards (1932)
Time spread of germination or Germination distribution	`TimeSpreadGerm`	It is the difference between time for last germination (t_g) and time for first germination (t_0). $$Time\,spread\,of\,germination = t_g - t_0$$	time	Germination time	Al-Mudaris (1998); Schrader and Graves (2000); Kader (2005)
Peak period of germination or Modal time of germination	`PeakGermTime`	It is the time in which highest frequency of germinated seeds are observed and need not be unique.	time	Germination time	Ranal and Santana (2006)
Median germination time (t_{50}) (Coolbear)	`t50`	It is the time to reach 50% of final/maximum germination. With argument method specified as `"coolbear"`, it is computed according to the formula by (Coolbear et al., 1984) as follows: $$t_{50} = T_i + \frac{(\frac{N+1}{2} - N_i)(T_j - T_i)}{N_j - N_i}$$ Where, t_{50} is the median germination time, N is the final number of germinated seeds and N_i and N_j are the total number of seeds germinated in adjacent counts at time T_i and T_j respectively, when $N_i < \frac{N+1}{2} < N_j$.	time	Germination time	Coolbear et al. (1984)

Germination index	function	Details	Unit	Measures	Reference
Median germination time (t_{50}) (Farooq)	`t50`	With argument method specified as `"farooq"`, it is computed according to the formula by (Coolbear et al., 1984) as follows: $$t_{50} = T_i + \frac{(\frac{N}{2} - N_i)(T_j - T_i)}{N_j - N_i}$$ Where, t_{50} is the median germination time, N is the final number of germinated seeds and N_i and N_j are the total number of seeds germinated in adjacent counts at time T_i and T_j respectively, when $N_i < \frac{N}{2} < N_j$.	time	Germination time	Farooq et al. (2005)
Mean germination time or Mean length of incubation time ($\overline{T}$) or Germination resistance (GR) or Sprouting index (SI)	`MeanGermTime`	It is the average length of time required for maximum germination of a seed lot and is estimated according to the following formula. $$\overline{T} = \frac{\sum_{i=1}^{k} N_i T_i}{\sum_{i=1}^{k} N_i}$$ Where, T_i is the time from the start of the experiment to the ith observation, N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation) and k is the last time of germination. It is the inverse of mean germination rate ($\overline{V}$). $$\overline{T} = \frac{1}{\overline{V}}$$	time	Germination time	Edmond and Drapala (1958); Czabator (1962); Smith and Millet (1964); Gordon (1969); Gordon (1971); Ellis and Roberts (1980) Labouriau (1983a); Ranal and Santana (2006)
Variance of germination time (s_T^2)	`VarGermTime`	It is computed according to the following formula. $$s_T^2 = \frac{\sum_{i=1}^{k} N_i (T_i - \overline{T})^2}{\sum_{i=1}^{k} N_i - 1}$$ Where, T_i is the time from the start of the experiment to the ith observation, N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation) and k is the last time of germination.	time	Germination time	Labouriau (1983a); Ranal and Santana (2006)

Germination index	function	Details	Unit	Measures	Reference
Standard error of germination time ($s_{\overline{T}}$)	`SEGermTime`	It signifies the accuracy of the calculation of the mean germination time. It is estimated according to the following formula: $$s_{\overline{T}} = \sqrt{\frac{s_T^2}{\sum_{i=1}^{k} N_i}}$$ Where, N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation) and k is the last time of germination.	time	Germination time	Labouriau (1983a); Ranal and Santana (2006)
Mean germination rate ($\overline{V}$)	`MeanGermRate`	It is computed according to the following formula: $$\overline{V} = \frac{\sum_{i=1}^{k} N_i}{\sum_{i=1}^{k} N_i T_i}$$ Where, T_i is the time from the start of the experiment to the ith observation, N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation) and k is the last time of germination. It is the inverse of mean germination time ($\overline{T}$). $$\overline{V} = \frac{1}{\overline{T}}$$	time^{-1}	Germination rate	Labouriau and Valadares (1976); Labouriau (1983b); Ranal and Santana (2006)
Coefficient of velocity of germination (CVG) or Coefficient of rate of germination (CRG) or Kotowski's coefficient of velocity	`CVG`	It is estimated according to the following formula. $$CVG = \frac{\sum_{i=1}^{k} N_i}{\sum_{i=1}^{k} N_i T_i} \times 100$$ $$CVG = \overline{V} \times 100$$ Where, T_i is the time from the start of the experiment to the ith observation, N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation) and k is the last time of germination.	% day^{-1}	Germination rate	Kotowski (1926), Nichols and Heydecker (1968); Bewley and Black (1994); Labouriau (1983b); Scott et al. (1984)
Variance of germination rate (s_V^2)	`VarGermRate`	It is calculated according to the following formula. $$s_V^2 = \overline{V}^4 \times s_T^2$$ Where, s_T^2 is the variance of germination time.	time^{-2}	Germination rate	Labouriau (1983b); Ranal and Santana (2006)

Germination index	function	Details	Unit	Measures	Reference
Standard error of germination rate ($s_{\overline{V}}$)	`SEGermRate`	It is estimated according to the following formula. $$s_{\overline{V}} = \sqrt{\frac{s_V^2}{\sum_{i=1}^{k} N_i}}$$ Where, N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation) and k is the last time of germination.	time^{-1}	Germination rate	Labouriau (1983b); Ranal and Santana (2006)
Germination rate as the reciprocal of the median time (v_{50})	`GermRateRecip`	It is the reciprocal of the median germination time (t_{50}). $$v_{50} = \frac{1}{t_{50}}$$	time^{-1}	Germination rate	Went (1957); Labouriau (1983b); Ranal and Santana (2006)
Speed of germination or Germination rate Index or index of velocity of germination or Emergence rate index (Germination index according to AOSA)	`GermSpeed`	It is the rate of germination in terms of the total number of seeds that germinate in a time interval. It is estimated as follows: $$S = \frac{N_1}{T_1} + \frac{N_2}{T_2} + \frac{N_3}{T_3} + \cdots + \frac{N_n}{T_n}$$ Where, N_1, N_2, N_3, $\cdots$, N_n are the number of germinated seeds observed at time (days or hours) T_1, T_2, T_3, $\cdots$, T_n after sowing. (Not accumulated/cumulative number, but the number of seeds that germinated at the specific time). Instead of germination counts, germination percentages may also be used for computation of speed of germination.	% time^{-1}	Mixed	Throneberry and Smith (1955); Maguire (1962); Allan et al. (1962); Kendrick and Frankland (1969); Bouton et al. (1976); AOSA (1983); Khandakar and Bradbeer (1983); Bradbeer (1988); Wardle et al. (1991)
Speed of accumulated germination	`GermSpeedAccumulat`	It is estimated as follows: $$S_{accumulated} = \frac{N_1}{T_1} + \frac{N_1 + N_2}{T_2} + \frac{N_1 + N_2 + N_3}{T_3} + \cdots + \frac{N_1 + N_2}{}$$ Where, N_1, N_2, N_3, $\cdots$, N_n are the number of germinated seeds observed at time (days or hours) T_1, T_2, T_3, $\cdots$, T_n after sowing. (Not accumulated/cumulative number, but the number of seeds that germinated at the specific time). Instead of germination counts, germination percentages may also be used for computation of speed of germination.	% time^{-1}	Mixed	Bradbeer (1988); Wardle et al. (1991); Haugland and Brandsaeter (1996); Santana and Ranal (2004)
Corrected germination rate index	`GermSpeedCorrected`	It is computed as follows: $$S_{corrected} = \frac{S}{FGP}$$ Where, FGP: the final germination percentage or germinability.	time^{-1}	Mixed	Evetts and Burnside (1972)

Germination index	function	Details	Unit	Measures	Reference
Weighted germination percentage (WGP)	`WeightGermPercent`	It is estimated as follows: $$WGP = \frac{\sum_{i=1}^{t}(t-i+1)N_i}{t \times N} \times 100$$ Where, N_i is the number of seeds that germinated in the time interval i (not cumulative, but partial count), N is the total number of seeds tested and t is the total number of time intervals.		Mixed	Reddy et al. (1985); Reddy (1978)
Mean germination percentage per unit time ($\overline{GP}$)	`MeanGermPercent`	It is estimated as follows: $$\overline{G} = \frac{GP}{T_n}$$ Where, GP is the final germination percentage and T_n is the total number of intervals(e.g. days) required for final germination.		Mixed	Czabator (1962)
Number of seeds germinated per unit time $\overline{N}$	`MeanGermNumber`	It is estimated as follows: $$\overline{N} = \frac{N_g}{T_n}$$ Where, N_g is the number of germinated seeds and $T_n$is the total number of intervals (e.g. days) required for final germination.		Mixed	Khamassi et al. (2013)
Timson's index [$\sum 10$ (Ten summation), $\sum 5$ or $\sum 20$] or Germination energy index (GEI)	`TimsonsIndex`	It is the progressive total of cumulative germination percentage recorded at specific intervals for a set period of time and is estimated in terms of cumulative germination percentage (G_i) as follows: $$\sum n = \sum_{i=1}^{t} G_i$$ Where, G_i is the cumulative germination percentage in time interval i and t is the total number of time intervals. It also estimated in terms of partial germination percentage as follows: $$\sum n = \sum_{i=1}^{t} g_i(t-j)$$ Where, g_i is the germination (not cumulative, but partial germination) in time interval i (i varying from 0 to t) and t is the total number of time intervals and $j = i - 1$.		Mixed	Grose and Zimmer (1958); Timson (1965); Brown and Mayer (1988); Baskin and Baskin (1998); Goodchild and Walker (1971)

Germination index	function	Details	Unit	Measures	Reference
Modified Timson's index (Labouriau)	`TimsonsIndex`	It is estimated as Timson's index T divided by the sum of partial germination percentages. $$T_{mod} = \frac{T}{\sum_{i=1}^{t} g_i}$$		Mixed	Ranal and Santana (2006)
Modified Timson's index (Khan and Unger)	`TimsonsIndex`	It is estimated as Timson's index (T) divided by the number of intervals (t). $$T_{mod} = \frac{T}{t}$$		Mixed	Khan and Ungar (1984)
George's index	`GermRateGeorge`	It is estimated as follows: $$GR = \sum_{i=1}^{t} N_i K_i$$ Where N_i is the number of seeds germinated by ith interval and K_i is the number of intervals(eg. days) until the end of the test.		Mixed	George (1961); Tucker and Wright (1965); Nichols and Heydecker (1968)
Peak value(PV) (Czabator) or Emergence Energy (EE)	`PeakValue`	It is the accumulated number of seeds germinated at the point on the germination curve at which the rate of germination starts to decrease. It is computed as the maximum quotient obtained by dividing successive cumulative germination values by the relevant incubation time.		Mixed	Czabator (1962); Bonner (1967)
Germination value (GV) (Czabator)	`GermValue`	It is computed as follows: $$GV = PV \times MDG$$ Where, PV is the peak value and MDG is the mean daily germination percentage from the onset of germination. It can also be computed for other time intervals of successive germination counts, by replacing MDG with the mean germination percentage per unit time ($\overline{GP}$).		Mixed	Czabator (1962)

Germination index	function	Details	Unit	Measures	Reference
Germination value (GV) (Diavanshir and Pourbiek)	`GermValue`	It is computed as follows: $$GV = \frac{\sum DGS}{N} \times GP \times k$$ Where, DGS is the daily germination speed computed by dividing cumulative germination percentage by the number of days since the since the onset of germination, N is the frequency or number of DGS calculated during the test, GP is the germination percentage expressed over 100 and k is a constant. The value of k is decided on the basis of average daily speed of germination ($\frac{\sum DGS}{N}$). If it is less than 10, then k value of 10 can be used and if it is more than 10, then value of 7 or 8 can be used for k. GV value can be modified (GV_{mod}), to consider the entire duration from the beginning of the test instead of just from the onset of germination.		Mixed	Djavanshir and Pourbeik (1976); Brown and Mayer (1988)
Coefficient of uniformity of germination (CUG)	`CUGerm`	It is computed as follows: $$CV_T = \frac{\sum_{i=1}^{k} N_i}{\sum_{i=1}^{k} (\overline{T} - T_i)^2 N_i}$$ Where, $\overline{T}$ is the the mean germination time, T_i is the time from the start of the experiment to the ith observation (day for the example); N_i is the number of seeds germinated in the ith time (not the accumulated number, but the number correspondent to the ith observation), and k is the last time of germination.		Germinatin unifromity	Heydecker (1972); Bewley and Black (1994)
Coefficient of variation of the germination time (CV_T)	`CVGermTime`	It is estimated as follows: $$CV_T = \sqrt{\frac{s_T^2}{\overline{T}}}$$ Where, s_T^2 is the variance of germination time and $\overline{T}$ is the mean germination time.		Germinatin unifromity	Ranal and Santana (2006)
Synchronization index ($\overline{E}$) or Uncertainty of the germination process (U) or informational entropy (H)	`GermUncertainty`	It is estimated as follows: $$\overline{E} = -\sum_{i=1}^{k} f_i \log_2 f_i$$ Where, f_i is the relative frequency of germination ($f_i = \frac{N_i}{\sum_{i=1}^{k} N_i}$), N_i is the number of seeds germinated on the ith time and k is the last day of observation.	bit	Germination synchrony	Shannon (1948); Labouriau and Valadares (1976); Labouriau (1983b)

Germination index	function	Details	Unit	Measures	Reference
Synchrony of germination (Z index)	`GermSynchrony`	It is computed as follows: $$Z = \frac{\sum_{i=1}^{k} C_{N_i,2}}{C_{\Sigma N_i,2}}$$ Where, $C_{N_i,2}$ is the partial combination of the two germinated seeds from among N_i, the number of seeds germinated on the ith time (estimated as $C_{N_i,2} = \frac{Ni(Ni-1)}{2}$) and $C_{\Sigma N_i,2}$ is the partial combination of the two germinated seeds from among the total number of seeds germinated at the final count, assuming that all seeds that germinated did so simultaneously.		Germination synchrony	Primack (1985); Ranal and Santana (2006)

Examples

GermPercent()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)

# From partial germination counts
GermPercent(germ.counts = x, total.seeds = 50)
```

```
[1] 80
```

```
# From cumulative germination counts
GermPercent(germ.counts = y, total.seeds = 50, partial = FALSE)
```

```
[1] 80
```

```
# From number of germinated seeds
GermPercent(germinated.seeds = 40, total.seeds = 50)
```

```
[1] 80
```

FirstGermTime(), LastGermTime(), PeakGermTime(), TimeSpreadGerm()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
z <- c(0, 0, 0, 0, 11, 11, 9, 7, 1, 0, 1, 0, 0, 0)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
FirstGermTime(germ.counts = x, intervals = int)
```

```
[1] 5
```

```
LastGermTime(germ.counts = x, intervals = int)
```

```
[1] 11
```

```
TimeSpreadGerm(germ.counts = x, intervals = int)
```

```
[1] 6
```

```
PeakGermTime(germ.counts = x, intervals = int)
```

```
[1] 6
```

```
# For multiple peak germination times
PeakGermTime(germ.counts = z, intervals = int)
```

```
Warning in PeakGermTime(germ.counts = z, intervals = int): Multiple peak
germination times exist.
```

```
[1] 5 6
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
FirstGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 5
```

```
LastGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 11
```

```
TimeSpreadGerm(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 6
```

```
PeakGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 6
```

```
# For multiple peak germination time
PeakGermTime(germ.counts = cumsum(z), intervals = int, partial = FALSE)
```

```
Warning in PeakGermTime(germ.counts = cumsum(z), intervals = int, partial =
FALSE): Multiple peak germination times exist.
```

```
[1] 5 6
```

t50()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
t50(germ.counts = x, intervals = int, method = "coolbear")
```

```
[1] 5.970588
```

```
t50(germ.counts = x, intervals = int, method = "farooq")
```

```
[1] 5.941176
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
t50(germ.counts = y, intervals = int, partial = FALSE, method = "coolbear")
```

```
[1] 5.970588
```

```
t50(germ.counts = y, intervals = int, partial = FALSE, method = "farooq")
```

```
[1] 5.941176
```

MeanGermTime(), VarGermTime(), SEGermTime(), CVGermTime()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
MeanGermTime(germ.counts = x, intervals = int)
```

```
[1] 6.7
```

```
VarGermTime(germ.counts = x, intervals = int)
```

```
[1] 1.446154
```

```
SEGermTime(germ.counts = x, intervals = int)
```

```
[1] 0.1901416
```

```
CVGermTime(germ.counts = x, intervals = int)
```

```
[1] 0.1794868
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
MeanGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 6.7
```

```
VarGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 19.04012
```

```
SEGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.2394781
```

```
CVGermTime(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.6512685
```

MeanGermRate(), CVG(), VarGermRate(), SEGermRate(), GermRateRecip()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
MeanGermRate(germ.counts = x, intervals = int)
```

```
[1] 0.1492537
```

```
CVG(germ.counts = x, intervals = int)
```

```
[1] 14.92537
```

```
VarGermRate(germ.counts = x, intervals = int)
```

```
[1] 0.0007176543
```

```
SEGermRate(germ.counts = x, intervals = int)
```

```
[1] 0.004235724
```

```
GermRateRecip(germ.counts = x, intervals = int, method = "coolbear")
```

```
[1] 0.1674877
```

```
GermRateRecip(germ.counts = x, intervals = int, method = "farooq")
```

```
[1] 0.1683168
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
MeanGermRate(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.1492537
```

```
CVG(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 14.92537
```

```
VarGermRate(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.009448666
```

```
SEGermRate(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.005334776
```

```
GermRateRecip(germ.counts = y, intervals = int,
              method = "coolbear", partial = FALSE)
```

```
[1] 0.1674877
```

```
GermRateRecip(germ.counts = y, intervals = int,
              method = "farooq", partial = FALSE)
```

```
[1] 0.1683168
```

GermSpeed(), GermSpeedAccumulated(), GermSpeedCorrected()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
GermSpeed(germ.counts = x, intervals = int)
```

```
[1] 6.138925
```

```
GermSpeedAccumulated(germ.counts = x, intervals = int)
```

```
[1] 34.61567
```

```
GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                   method = "normal")
```

```
[1] 0.07673656
```

```
GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                   method = "accumulated")
```

```
[1] 0.4326958
```

```
# From partial germination counts (with percentages instead of counts)
#-------------------------------------------------------------------------
GermSpeed(germ.counts = x, intervals = int,
          percent = TRUE, total.seeds = 50)
```

```
[1] 12.27785
```

```
GermSpeedAccumulated(germ.counts = x, intervals = int,
                     percent = TRUE, total.seeds = 50)
```

```
[1] 69.23134
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
GermSpeed(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 6.138925
```

```
GermSpeedAccumulated(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 34.61567
```

```
GermSpeedCorrected(germ.counts = y, intervals = int,
                   partial = FALSE, total.seeds = 50, method = "normal")
```

```
[1] 0.07673656
```

```
GermSpeedCorrected(germ.counts = y, intervals = int,
                   partial = FALSE, total.seeds = 50, method = "accumulated")
```

```
[1] 0.4326958
```

```
# From cumulative germination counts (with percentages instead of counts)
#-------------------------------------------------------------------------
GermSpeed(germ.counts = y, intervals = int, partial = FALSE,
          percent = TRUE, total.seeds = 50)
```

```
[1] 12.27785
```

```
GermSpeedAccumulated(germ.counts = y, intervals = int, partial = FALSE,
                     percent = TRUE, total.seeds = 50)
```

```
[1] 69.23134
```

GermSpeed(), GermSpeedAccumulated(), GermSpeedCorrected()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
GermSpeed(germ.counts = x, intervals = int)
```

```
[1] 6.138925
```

```
GermSpeedAccumulated(germ.counts = x, intervals = int)
```

```
[1] 34.61567
```

```
GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                   method = "normal")
```

```
[1] 0.07673656
```

```
GermSpeedCorrected(germ.counts = x, intervals = int, total.seeds = 50,
                   method = "accumulated")
```

```
[1] 0.4326958
```

```
# From partial germination counts (with percentages instead of counts)
#-------------------------------------------------------------------------
```

```
GermSpeed(germ.counts = x, intervals = int,
          percent = TRUE, total.seeds = 50)
```

```
[1] 12.27785
```

```
GermSpeedAccumulated(germ.counts = x, intervals = int,
                     percent = TRUE, total.seeds = 50)
```

```
[1] 69.23134
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
GermSpeed(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 6.138925
```

```
GermSpeedAccumulated(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 34.61567
```

```
GermSpeedCorrected(germ.counts = y, intervals = int,
                   partial = FALSE, total.seeds = 50, method = "normal")
```

```
[1] 0.07673656
```

```
GermSpeedCorrected(germ.counts = y, intervals = int,
                   partial = FALSE, total.seeds = 50, method = "accumulated")
```

```
[1] 0.4326958
```

```
# From cumulative germination counts (with percentages instead of counts)
#-------------------------------------------------------------------------
GermSpeed(germ.counts = y, intervals = int, partial = FALSE,
          percent = TRUE, total.seeds = 50)
```

```
[1] 12.27785
```

```
GermSpeedAccumulated(germ.counts = y, intervals = int, partial = FALSE,
                     percent = TRUE, total.seeds = 50)
```

```
[1] 69.23134
```

WeightGermPercent()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
WeightGermPercent(germ.counts = x, total.seeds = 50, intervals = int)
```

```
[1] 47.42857
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
WeightGermPercent(germ.counts = y, total.seeds = 50, intervals = int,
                  partial = FALSE)
```

```
[1] 47.42857
```

MeanGermPercent(), MeanGermNumber()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------------
MeanGermPercent(germ.counts = x, total.seeds = 50, intervals = int)
```

```
[1] 5.714286
```

```
MeanGermNumber(germ.counts = x, intervals = int)
```

```
[1] 2.857143
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------------
MeanGermPercent(germ.counts = y, total.seeds = 50, intervals = int, partial = FALSE)
```

```
[1] 5.714286
```

```
MeanGermNumber(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 2.857143
```

```
# From number of germinated seeds
#-------------------------------------------------------------------------------
MeanGermPercent(germinated.seeds = 40, total.seeds = 50, intervals = int)
```

```
[1] 5.714286
```

TimsonsIndex(), GermRateGeorge()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------------
# Wihout max specified
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50)
```

```
[1] 664
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
             modification = "none")
```

```
[1] 664
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
             modification = "labouriau")
```

```
[1] 8.3
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
             modification = "khanungar")
```

```
[1] 47.42857
```

```
# With max specified
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50, max = 10)
```

```
[1] 344
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
             max = 10, modification = "none")
```

```
[1] 344
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
             max = 10, modification = "labouriau")
```

```
[1] 4.410256
```

```
TimsonsIndex(germ.counts = x, intervals = int, total.seeds = 50,
             max = 10, modification = "khanungar")
```

```
[1] 24.57143
```

```
# Wihout max specified
GermRateGeorge(germ.counts = x, intervals = int)
```

```
[1] 332
```

```
# With max specified
GermRateGeorge(germ.counts = x, intervals = int, max = 10)
```

```
[1] 172
```

```
GermRateGeorge(germ.counts = x, intervals = int, max = 14)
```

```
[1] 332
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------------


# Wihout max specified
GermRateGeorge(germ.counts = x, intervals = int, partial = TRUE)
```

```
[1] 332
```

```
# With max specified
GermRateGeorge(germ.counts = x, intervals = int, partial = TRUE, max = 10)
```

```
[1] 172
```

```
GermRateGeorge(germ.counts = x, intervals = int, partial = TRUE, max = 14)
```

```
[1] 332
```

PeakValue(), GermValue()

```
x <- c(0, 0, 34, 40, 21, 10, 4, 5, 3, 5, 8, 7, 7, 6, 6, 4, 0, 2, 0, 2)
y <- c(0, 0, 34, 74, 95, 105, 109, 114, 117, 122, 130, 137, 144, 150,
       156, 160, 160, 162, 162, 164)
int <- 1:length(x)
total.seeds = 200

# From partial germination counts
```

```
#-------------------------------------------------------------------------
PeakValue(germ.counts = x, intervals = int, total.seeds = 200)
```

```
[1] 9.5
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
          method = "czabator")
```

```
$`Germination Value`
[1] 38.95

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
3           34         3                     34                    17.0
4           40         4                     74                    37.0
5           21         5                     95                    47.5
6           10         6                    105                    52.5
7            4         7                    109                    54.5
8            5         8                    114                    57.0
9            3         9                    117                    58.5
10           5        10                    122                    61.0
11           8        11                    130                    65.0
12           7        12                    137                    68.5
13           7        13                    144                    72.0
14           6        14                    150                    75.0
15           6        15                    156                    78.0
16           4        16                    160                    80.0
17           0        17                    160                    80.0
18           2        18                    162                    81.0
19           0        19                    162                    81.0
20           2        20                    164                    82.0
        DGS
3  5.666667
4  9.250000
5  9.500000
6  8.750000
7  7.785714
8  7.125000
9  6.500000
10 6.100000
11 5.909091
12 5.708333
13 5.538462
14 5.357143
15 5.200000
16 5.000000
17 4.705882
18 4.500000
19 4.263158
20 4.100000
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
          method = "dp", k = 10)
```

```
$`Germination Value`
```

```
[1] 53.36595

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
3           34         3                     34                    17.0
4           40         4                     74                    37.0
5           21         5                     95                    47.5
6           10         6                    105                    52.5
7            4         7                    109                    54.5
8            5         8                    114                    57.0
9            3         9                    117                    58.5
10           5        10                    122                    61.0
11           8        11                    130                    65.0
12           7        12                    137                    68.5
13           7        13                    144                    72.0
14           6        14                    150                    75.0
15           6        15                    156                    78.0
16           4        16                    160                    80.0
17           0        17                    160                    80.0
18           2        18                    162                    81.0
19           0        19                    162                    81.0
20           2        20                    164                    82.0
        DGS SumDGSbyN        GV
3  5.666667  5.666667  9.633333
4  9.250000  7.458333 27.595833
5  9.500000  8.138889 38.659722
6  8.750000  8.291667 43.531250
7  7.785714  8.190476 44.638095
8  7.125000  8.012897 45.673512
9  6.500000  7.796769 45.611097
10 6.100000  7.584673 46.266503
11 5.909091  7.398497 48.090230
12 5.708333  7.229481 49.521942
13 5.538462  7.075752 50.945411
14 5.357143  6.932534 51.994006
15 5.200000  6.799262 53.034246
16 5.000000  6.670744 53.365948
17 4.705882  6.539753 52.318022
18 4.500000  6.412268 51.939373
19 4.263158  6.285850 50.915385
20 4.100000  6.164414 50.548194

$testend
[1] 16
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
          method = "czabator", from.onset = FALSE)
```

```
$`Germination Value`
[1] 38.95

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
1            0         1                     0                     0.0
2            0         2                     0                     0.0
```

```
3           34         3                   34                   17.0
4           40         4                   74                   37.0
5           21         5                   95                   47.5
6           10         6                  105                   52.5
7            4         7                  109                   54.5
8            5         8                  114                   57.0
9            3         9                  117                   58.5
10           5        10                  122                   61.0
11           8        11                  130                   65.0
12           7        12                  137                   68.5
13           7        13                  144                   72.0
14           6        14                  150                   75.0
15           6        15                  156                   78.0
16           4        16                  160                   80.0
17           0        17                  160                   80.0
18           2        18                  162                   81.0
19           0        19                  162                   81.0
20           2        20                  164                   82.0
        DGS
1  0.000000
2  0.000000
3  5.666667
4  9.250000
5  9.500000
6  8.750000
7  7.785714
8  7.125000
9  6.500000
10 6.100000
11 5.909091
12 5.708333
13 5.538462
14 5.357143
15 5.200000
16 5.000000
17 4.705882
18 4.500000
19 4.263158
20 4.100000
```

```
GermValue(germ.counts = x, intervals = int, total.seeds = 200,
          method = "dp", k = 10, from.onset = FALSE)
```

```
$`Germination Value`
[1] 46.6952

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
1            0         1                     0                     0.0
2            0         2                     0                     0.0
3           34         3                    34                    17.0
4           40         4                    74                    37.0
5           21         5                    95                    47.5
6           10         6                   105                    52.5
7            4         7                   109                    54.5
```

```
8            5         8                   114                   57.0
9            3         9                   117                   58.5
10           5        10                   122                   61.0
11           8        11                   130                   65.0
12           7        12                   137                   68.5
13           7        13                   144                   72.0
14           6        14                   150                   75.0
15           6        15                   156                   78.0
16           4        16                   160                   80.0
17           0        17                   160                   80.0
18           2        18                   162                   81.0
19           0        19                   162                   81.0
20           2        20                   164                   82.0
        DGS SumDGSbyN        GV
1  0.000000  0.000000  0.000000
2  0.000000  0.000000  0.000000
3  5.666667  1.888889  3.211111
4  9.250000  3.729167 13.797917
5  9.500000  4.883333 23.195833
6  8.750000  5.527778 29.020833
7  7.785714  5.850340 31.884354
8  7.125000  6.009673 34.255134
9  6.500000  6.064153 35.475298
10 6.100000  6.067738 37.013202
11 5.909091  6.053316 39.346552
12 5.708333  6.024567 41.268285
13 5.538462  5.987174 43.107655
14 5.357143  5.942172 44.566291
15 5.200000  5.892694 45.963013
16 5.000000  5.836901 46.695205
17 4.705882  5.770370 46.162961
18 4.500000  5.699794 46.168331
19 4.263158  5.624182 45.555871
20 4.100000  5.547972 45.493374

$testend
[1] 16
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
PeakValue(germ.counts = y, interval = int, total.seeds = 200,
          partial = FALSE)
```

```
[1] 9.5
```

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
          partial = FALSE, method = "czabator")
```

```
$`Germination Value`
[1] 38.95

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
3           34         3                    34                   17.0
4           40         4                    74                   37.0
```

```
5           21         5                    95                  47.5
6           10         6                   105                  52.5
7            4         7                   109                  54.5
8            5         8                   114                  57.0
9            3         9                   117                  58.5
10           5        10                   122                  61.0
11           8        11                   130                  65.0
12           7        12                   137                  68.5
13           7        13                   144                  72.0
14           6        14                   150                  75.0
15           6        15                   156                  78.0
16           4        16                   160                  80.0
17           0        17                   160                  80.0
18           2        18                   162                  81.0
19           0        19                   162                  81.0
20           2        20                   164                  82.0
        DGS
3  5.666667
4  9.250000
5  9.500000
6  8.750000
7  7.785714
8  7.125000
9  6.500000
10 6.100000
11 5.909091
12 5.708333
13 5.538462
14 5.357143
15 5.200000
16 5.000000
17 4.705882
18 4.500000
19 4.263158
20 4.100000
```

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
          partial = FALSE, method = "dp", k = 10)
```

```
$`Germination Value`
[1] 53.36595

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
3           34         3                    34                  17.0
4           40         4                    74                  37.0
5           21         5                    95                  47.5
6           10         6                   105                  52.5
7            4         7                   109                  54.5
8            5         8                   114                  57.0
9            3         9                   117                  58.5
10           5        10                   122                  61.0
11           8        11                   130                  65.0
12           7        12                   137                  68.5
13           7        13                   144                  72.0
```

```
14           6        14                  150                  75.0
15           6        15                  156                  78.0
16           4        16                  160                  80.0
17           0        17                  160                  80.0
18           2        18                  162                  81.0
19           0        19                  162                  81.0
20           2        20                  164                  82.0
        DGS SumDGSbyN        GV
3  5.666667  5.666667  9.633333
4  9.250000  7.458333 27.595833
5  9.500000  8.138889 38.659722
6  8.750000  8.291667 43.531250
7  7.785714  8.190476 44.638095
8  7.125000  8.012897 45.673512
9  6.500000  7.796769 45.611097
10 6.100000  7.584673 46.266503
11 5.909091  7.398497 48.090230
12 5.708333  7.229481 49.521942
13 5.538462  7.075752 50.945411
14 5.357143  6.932534 51.994006
15 5.200000  6.799262 53.034246
16 5.000000  6.670744 53.365948
17 4.705882  6.539753 52.318022
18 4.500000  6.412268 51.939373
19 4.263158  6.285850 50.915385
20 4.100000  6.164414 50.548194

$testend
[1] 16
```

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
          partial = FALSE, method = "czabator", from.onset = FALSE)
```

```
$`Germination Value`
[1] 38.95

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
1            0         1                     0                     0.0
2            0         2                     0                     0.0
3           34         3                    34                    17.0
4           40         4                    74                    37.0
5           21         5                    95                    47.5
6           10         6                   105                    52.5
7            4         7                   109                    54.5
8            5         8                   114                    57.0
9            3         9                   117                    58.5
10           5        10                   122                    61.0
11           8        11                   130                    65.0
12           7        12                   137                    68.5
13           7        13                   144                    72.0
14           6        14                   150                    75.0
15           6        15                   156                    78.0
16           4        16                   160                    80.0
17           0        17                   160                    80.0
```

```
18           2        18                   162                   81.0
19           0        19                   162                   81.0
20           2        20                   164                   82.0
        DGS
1  0.000000
2  0.000000
3  5.666667
4  9.250000
5  9.500000
6  8.750000
7  7.785714
8  7.125000
9  6.500000
10 6.100000
11 5.909091
12 5.708333
13 5.538462
14 5.357143
15 5.200000
16 5.000000
17 4.705882
18 4.500000
19 4.263158
20 4.100000
```

```
GermValue(germ.counts = y, intervals = int, total.seeds = 200,
          partial = FALSE, method = "dp", k = 10, from.onset = FALSE)
```

```
$`Germination Value`
[1] 46.6952

[[2]]
   germ.counts intervals Cumulative.germ.counts Cumulative.germ.percent
1            0         1                     0                     0.0
2            0         2                     0                     0.0
3           34         3                    34                    17.0
4           40         4                    74                    37.0
5           21         5                    95                    47.5
6           10         6                   105                    52.5
7            4         7                   109                    54.5
8            5         8                   114                    57.0
9            3         9                   117                    58.5
10           5        10                   122                    61.0
11           8        11                   130                    65.0
12           7        12                   137                    68.5
13           7        13                   144                    72.0
14           6        14                   150                    75.0
15           6        15                   156                    78.0
16           4        16                   160                    80.0
17           0        17                   160                    80.0
18           2        18                   162                    81.0
19           0        19                   162                    81.0
20           2        20                   164                    82.0
        DGS SumDGSbyN        GV
1  0.000000  0.000000  0.000000
```

```
2  0.000000  0.000000  0.000000
3  5.666667  1.888889  3.211111
4  9.250000  3.729167 13.797917
5  9.500000  4.883333 23.195833
6  8.750000  5.527778 29.020833
7  7.785714  5.850340 31.884354
8  7.125000  6.009673 34.255134
9  6.500000  6.064153 35.475298
10 6.100000  6.067738 37.013202
11 5.909091  6.053316 39.346552
12 5.708333  6.024567 41.268285
13 5.538462  5.987174 43.107655
14 5.357143  5.942172 44.566291
15 5.200000  5.892694 45.963013
16 5.000000  5.836901 46.695205
17 4.705882  5.770370 46.162961
18 4.500000  5.699794 46.168331
19 4.263158  5.624182 45.555871
20 4.100000  5.547972 45.493374

$testend
[1] 16
```

CUGerm()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
CUGerm(germ.counts = x, intervals = int)
```

```
[1] 0.7092199
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
CUGerm(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.05267935
```

GermSynchrony(), GermUncertainty()

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)

# From partial germination counts
#-------------------------------------------------------------------------
GermSynchrony(germ.counts = x, intervals = int)
```

```
[1] 0.2666667
```

```
GermUncertainty(germ.counts = x, intervals = int)
```

```
[1] 2.062987
```

```
# From cumulative germination counts
#-------------------------------------------------------------------------
GermSynchrony(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 0.2666667
```

```
GermUncertainty(germ.counts = y, intervals = int, partial = FALSE)
```

```
[1] 2.062987
```

Curve fitting

Several mathematical functions have been used to fit the cumulative germination count data and describe the germination process such as Richard's, Weibull, logistic, log-logistic, gaussian, four-parameter hill function etc. Currently `germinationmetrics` implements the four-parameter hill function to fit the count data and computed various associated metrics.

Four-parameter hill function

The four-parameter hill function defined as follows (El-Kassaby et al., 2008):

$$f(x) = y = y_0 + \frac{ax^b}{x^b + c^b}$$

Where, y is the cumulative germination percentage at time x, y_0 is the intercept on the y axis, a is the asymptote, b is a mathematical parameter controlling the shape and steepness of the germination curve and c is the "half-maximal activation level".

The details of various parameters that are computed from this function are given in Table 4.

Table 4 Germination parameters estimated from the four-parameter hill function.

Germination parameters	Details	Unit	Measures
y intercept (y_0)	The intercept on the y axis.		
Asymptote (a)	It is the maximum cumulative germination percentage, which is equivalent to germination capacity.	%	Germination capacity
Shape and steepness (b)	Mathematical parameter controlling the shape and steepness of the germination curve. The larger the b , the steeper the rise toward the asymptote a, and the shorter the time between germination onset and maximum germination.		Germination rate
Half-maximal activation level (c)	Time required for 50% of viable seeds to germinate.	time	Germination time
lag	It is the time at germination onset and is computed by solving four-parameter hill function after setting y to 0 as follows: $$lag = b\sqrt{\frac{-y_0 c^b}{a + y_0}}$$	time	Germination time
D_{lag-50}	The duration between the time at germination onset (lag) and that at 50% germination (c).	time	Germination time

Germination parameters	Details	Unit	Measures
$t_{50_{total}}$	Time required for 50% of total seeds to germinate.	time	Germination time
$t_{50_{germinated}}$	Time required for 50% of viable/germinated seeds to germinate	time	Germination time
$t_{x_{total}}$	Time required for x% of total seeds to germinate.	time	Germination time
$t_{x_{germinated}}$	Time required for x% of viable/germinated seeds to germinate	time	Germination time
Uniformity ($U_{t_{max}-t_{min}}$)	It is the time interval between the percentages of viable seeds specified in the arguments `umin` and `umin` to germinate.	time	Germination time
Time at maximum germination rate ($TMGR$)	The partial derivative of the four-parameter hill function gives the instantaneous rate of germination (s) as follows: $$s = \frac{\partial y}{\partial x} = \frac{abc^b x^{b-1}}{(c^b + x^b)^2}$$ From this function for instantaneous rate of germination, $TMGR$ can be estimated as follows: $$TMGR = b\sqrt{\frac{c^b(b-1)}{b+1}}$$ It represents the point in time when the instantaneous rate of germination starts to decline.	time	Germination time
Area under the curve (AUC)	It is obtained by integration of the fitted curve between time 0 and time specified in the argument `tmax`.		Mixed
MGT	Calculated by integration of the fitted curve and proper normalisation.	time	Germination time
Skewness	It is computed as follows: $$\frac{MGT}{t_{50_{germinated}}}$$		

Examples

```
FourPHFfit()
```

```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
total.seeds = 50

# From partial germination counts
#-------------------------------------------------------------------------
FourPHFfit(germ.counts = x, intervals = int, total.seeds = 50, tmax = 20)
```

```
$data
```

```
   gp csgp intervals
1   0    0         1
2   0    0         2
3   0    0         3
4   0    0         4
5   8    8         5
6  34   42         6
7  20   62         7
8  14   76         8
9   2   78         9
10  0   78        10
11  2   80        11
12  0   80        12
13  0   80        13
14  0   80        14

$Parameters
  term  estimate  std.error statistic      p.value
1    a 80.000000 1.24158595  64.43372 1.973240e-14
2    b  9.881947 0.70779379  13.96162 6.952322e-08
3    c  6.034954 0.04952654 121.85294 3.399385e-17
4   y0  0.000000 0.91607007   0.00000 1.000000e+00

$Fit
     sigma isConv       finTol    logLik      AIC      BIC deviance
1 1.769385   TRUE 1.490116e-08 -25.49868 60.99736 64.19265 31.30723
  df.residual
1          10

$a
[1] 80

$b
[1] 9.881947

$c
[1] 6.034954

$y0
[1] 0

$lag
[1] 0

$Dlag50
[1] 6.034954

$t50.total
[1] 6.355122

$txp.total
[1] 4.956266 6.744598

$t50.Germinated
```

```
[1] 6.034954

$txp.Germinated
[1] 4.831809 6.287724

$Uniformity
        90         10 uniformity
  7.537688   4.831809   2.705880

$TMGR
[1] 5.912195

$AUC
[1] 1108.975

$MGT
[1] 6.632252

$Skewness
[1] 1.098973

$msg
[1] "#1. Relative error in the sum of squares is at most `ftol'. "

$isConv
[1] TRUE

attr(,"class")
[1] "FourPHFfit"
```

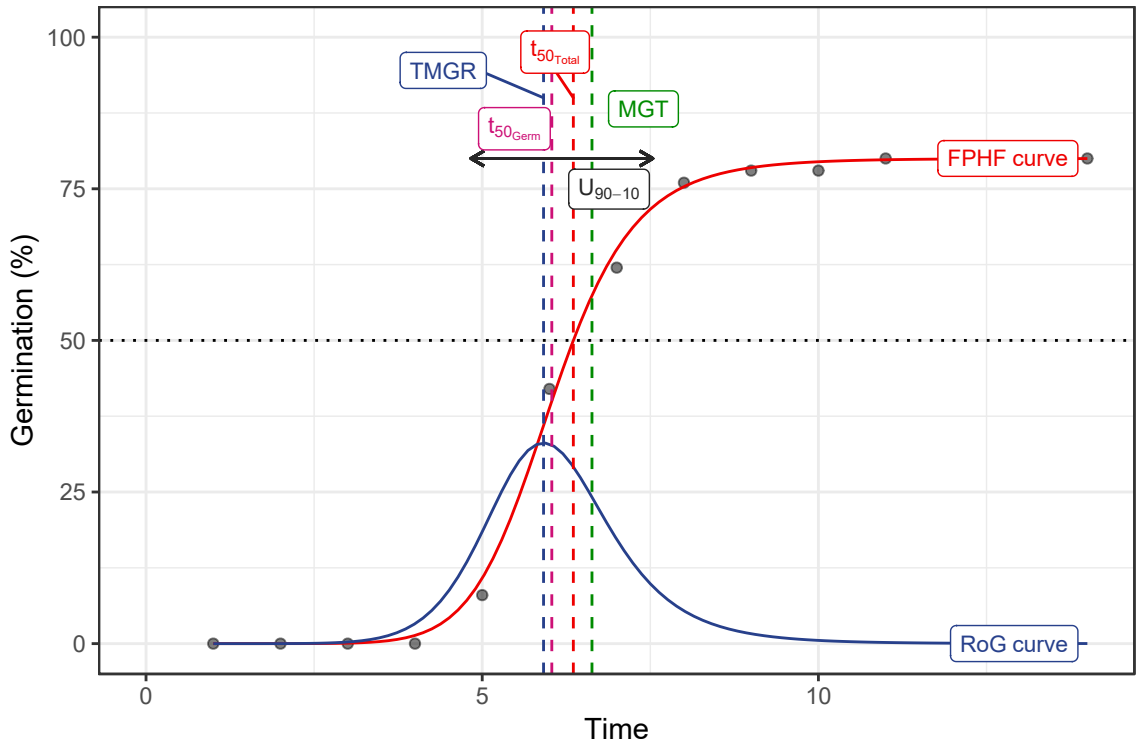
```
# From cumulative germination counts
#-------------------------------------------------------------------------
FourPHFfit(germ.counts = y, intervals = int, total.seeds = 50, tmax = 20,
partial = FALSE)
```

```
$data
   gp csgp intervals
1   0    0         1
2   0    0         2
3   0    0         3
4   0    0         4
5   8    8         5
6  34   42         6
7  20   62         7
8  14   76         8
9   2   78         9
10  0   78        10
11  2   80        11
12  0   80        12
13  0   80        13
14  0   80        14

$Parameters
  term  estimate std.error statistic      p.value
1    a 80.000000 1.2415867  64.43368 1.973252e-14
```

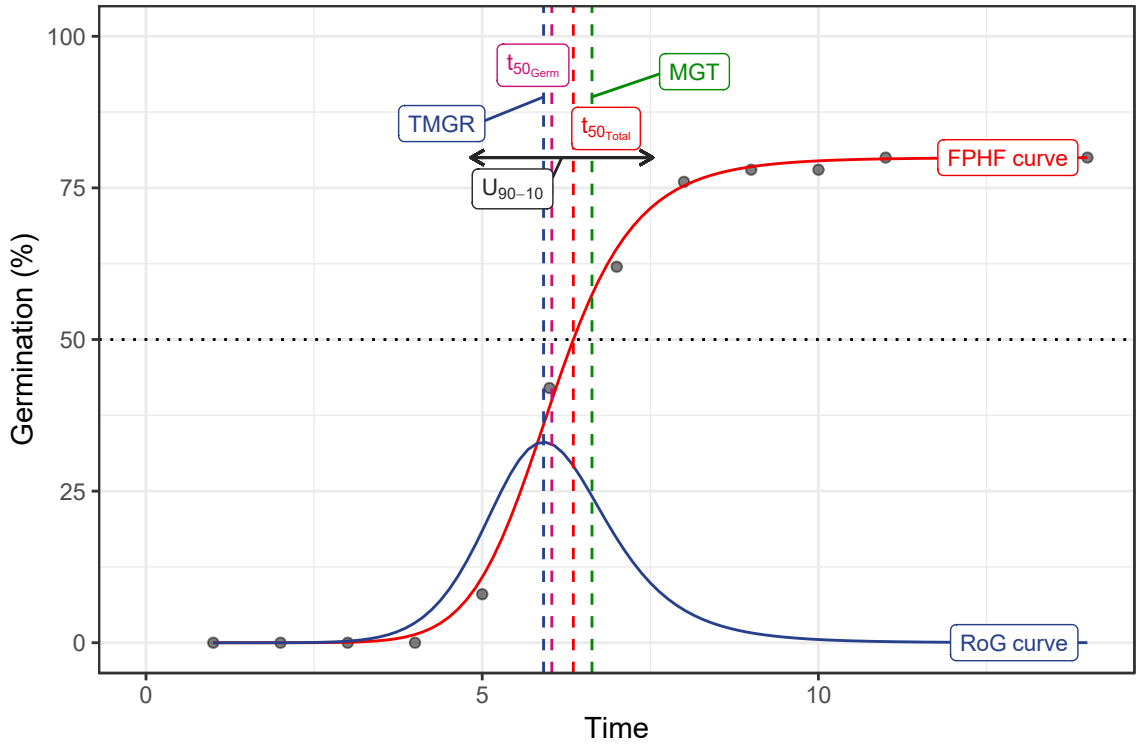
```
2    b  9.881927 0.7077918  13.96163 6.952270e-08
3    c  6.034953 0.0495266 121.85275 3.399437e-17
4   y0  0.000000 0.9160705   0.00000 1.000000e+00

$Fit
     sigma isConv       finTol    logLik      AIC      BIC deviance
1 1.769385   TRUE 1.490116e-08 -25.49868 60.99736 64.19265 31.30723
  df.residual
1          10

$a
[1] 80

$b
[1] 9.881927

$c
[1] 6.034953

$y0
[1] 0

$lag
[1] 0

$Dlag50
[1] 6.034953

$t50.total
[1] 6.355121

$txp.total
[1] 4.956263 6.744599

$t50.Germinated
[1] 6.034953

$txp.Germinated
[1] 4.831806 6.287723

$Uniformity
        90         10 uniformity
  7.537691   4.831806   2.705885

$TMGR
[1] 5.912194

$AUC
[1] 1108.976

$MGT
[1] 6.632252

$Skewness
```

```
[1] 1.098973

$msg
[1] "#1. Relative error in the sum of squares is at most `ftol'. "

$isConv
[1] TRUE

attr(,"class")
[1] "FourPHFfit"
```

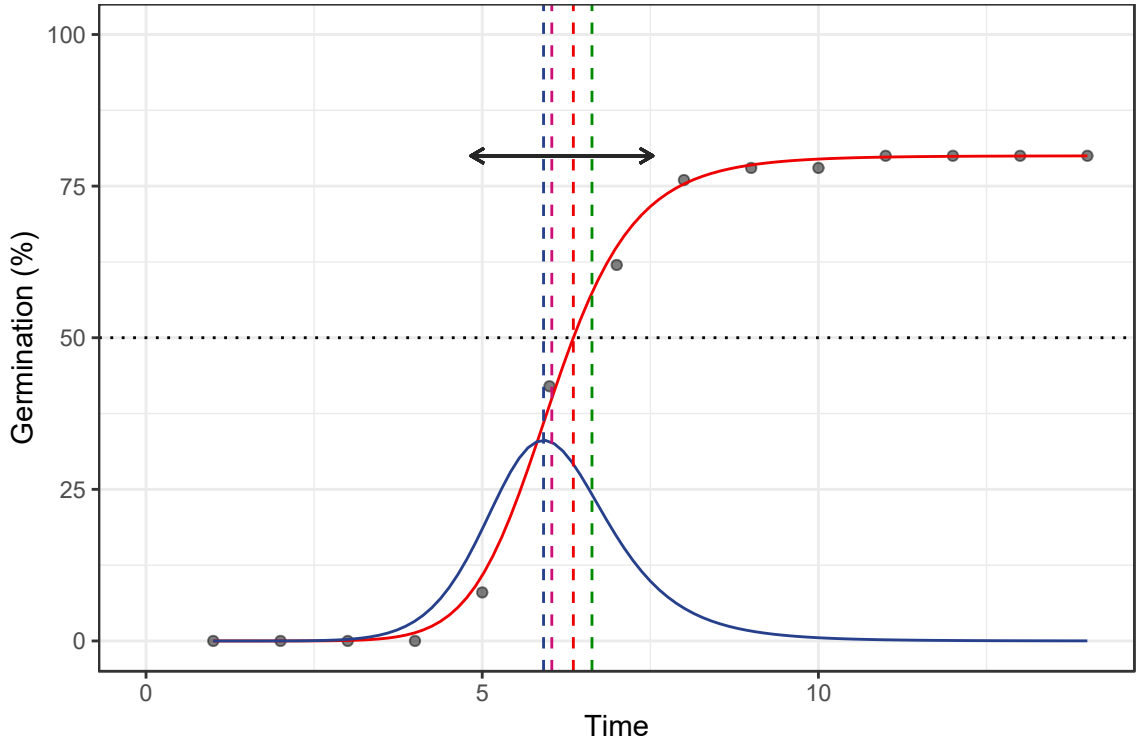
```
x <- c(0, 0, 0, 0, 4, 17, 10, 7, 1, 0, 1, 0, 0, 0)
y <- c(0, 0, 0, 0, 4, 21, 31, 38, 39, 39, 40, 40, 40, 40)
int <- 1:length(x)
total.seeds = 50

# From partial germination counts
#-------------------------------------------------------------------------------
fit1 <- FourPHFfit(germ.counts = x, intervals = int,
                   total.seeds = 50, tmax = 20)

# From cumulative germination counts
#-------------------------------------------------------------------------------
fit2 <- FourPHFfit(germ.counts = y, intervals = int,
                   total.seeds = 50, tmax = 20, partial = FALSE)

# Default plots
plot(fit1)
```



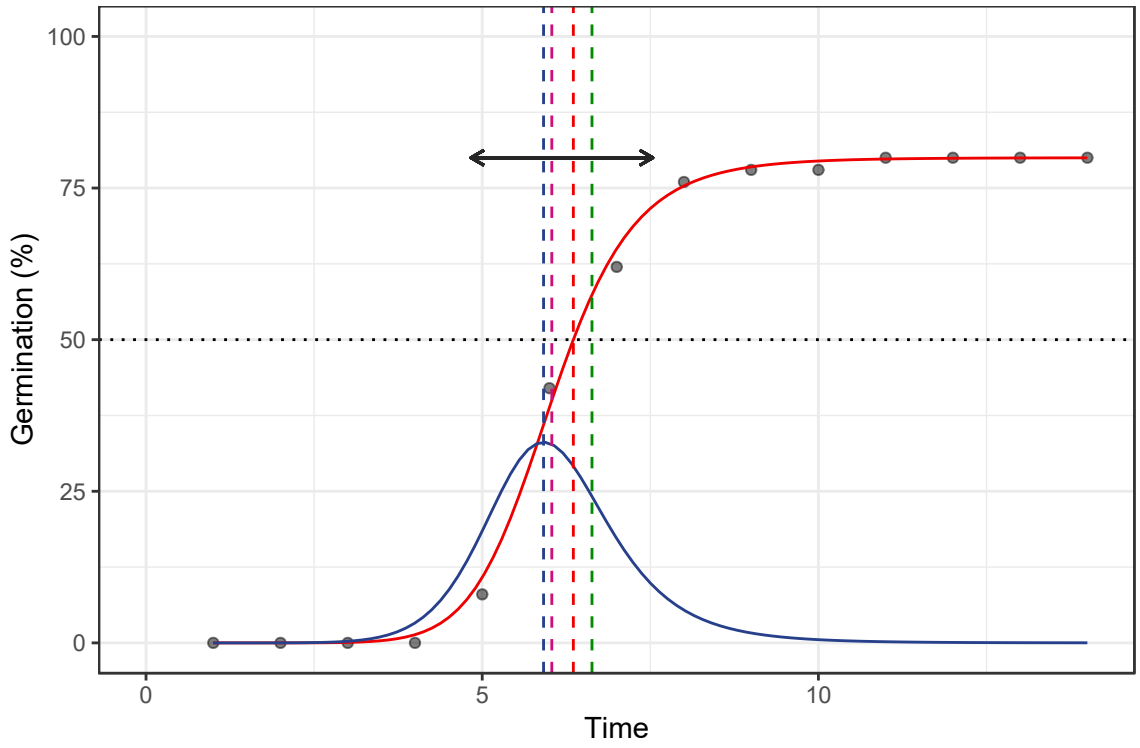
```
plot(fit2)
```



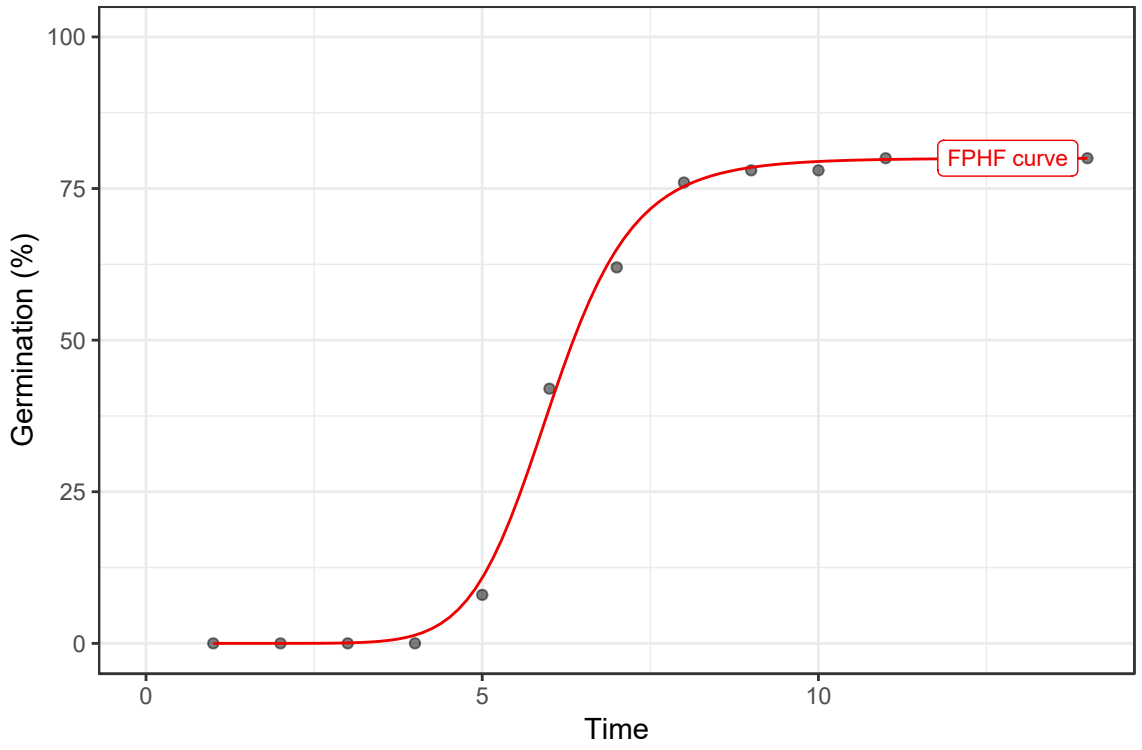

```
# No labels
plot(fit1, plotlabels = FALSE)
```



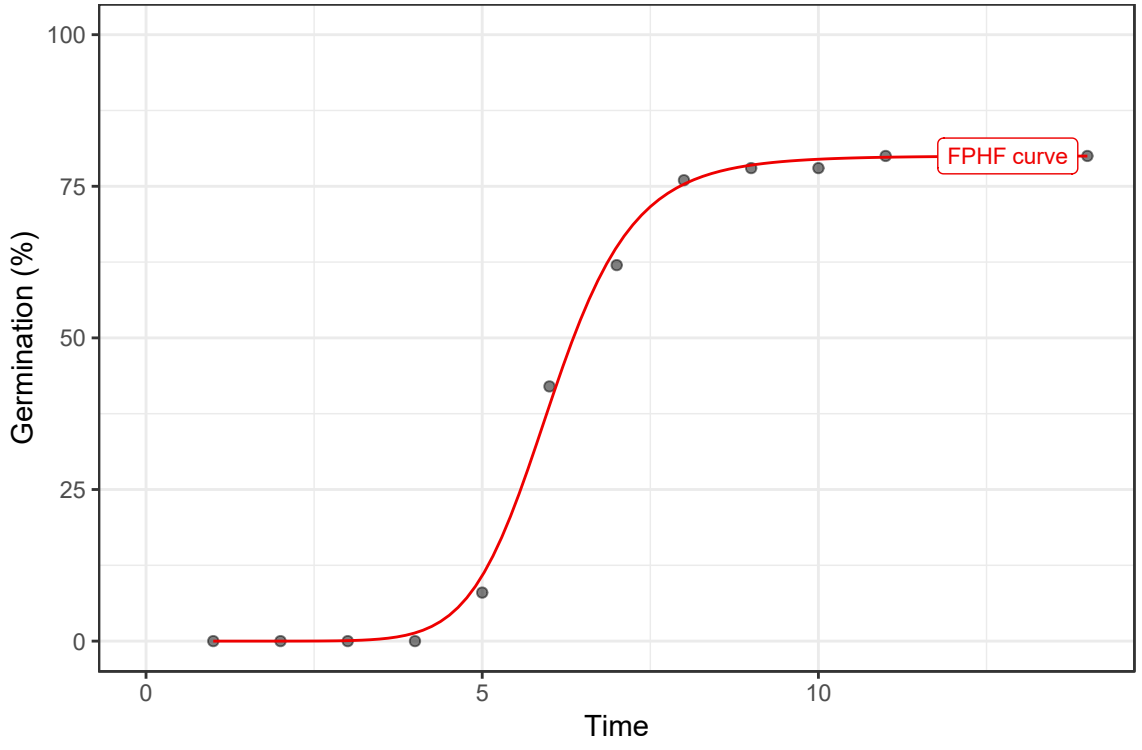
```
plot(fit2, plotlabels = FALSE)
```



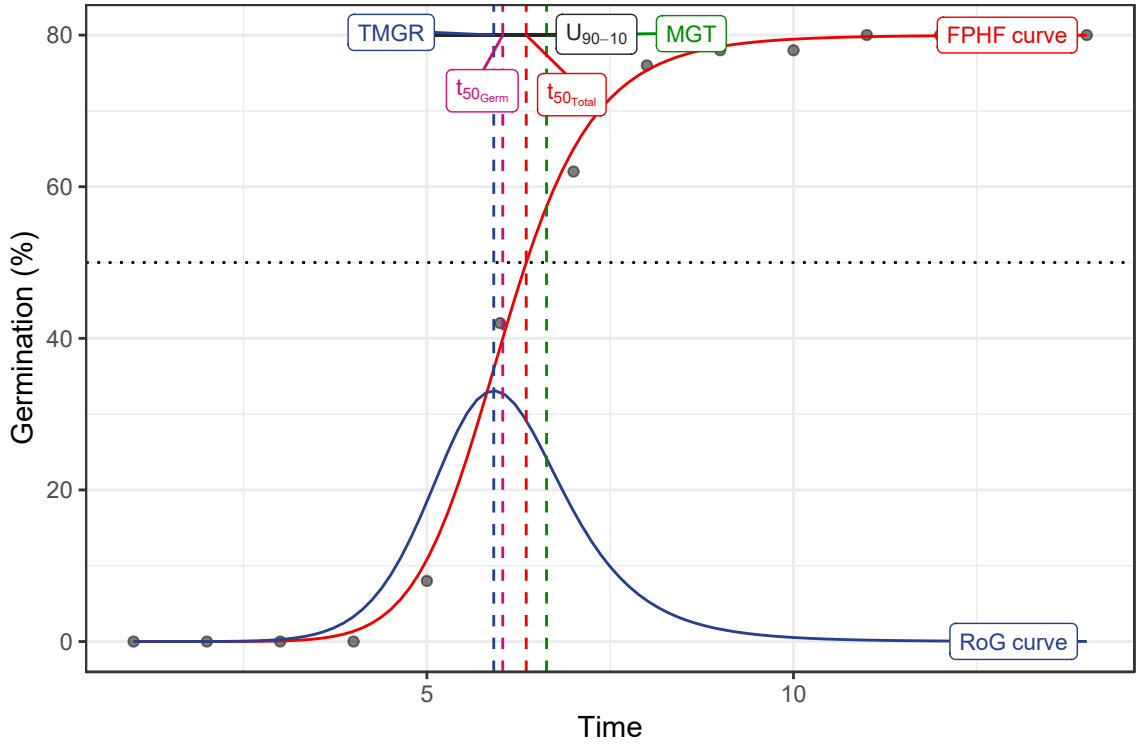

```
# Only the FPHF curve
plot(fit1, rog = FALSE, t50.total = FALSE, t50.germ = FALSE,
     tmgr = FALSE, mgt = FALSE, uniformity = FALSE)
```



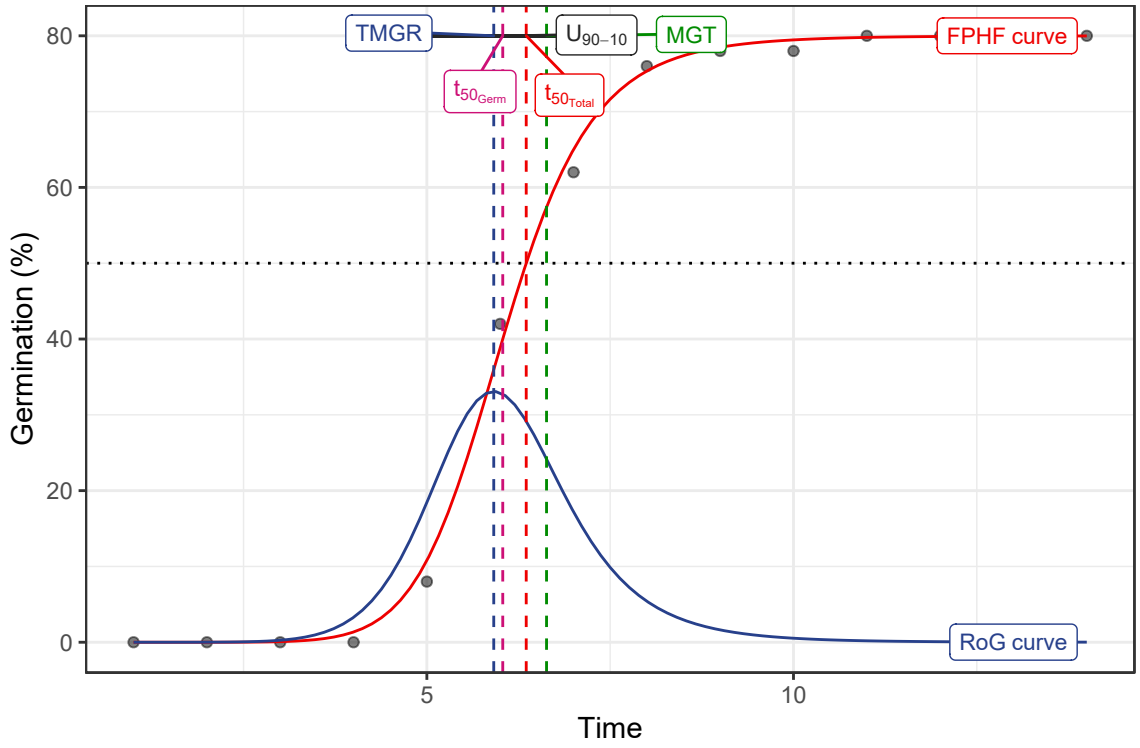

```
plot(fit2, rog = FALSE, t50.total = FALSE, t50.germ = FALSE,
     tmgr = FALSE, mgt = FALSE, uniformity = FALSE)
```




```
# Without y axis limits adjustment
plot(fit1, limits = FALSE)
```




```
plot(fit2, limits = FALSE)
```



Wrapper function

The wrapper function `germination.indices()` can be used to compute multiple germination indices from a data frame of germination counts recorded at specific time intervals for multiple samples in batch.

germination.indices()

```
data(gcdata)

counts.per.intervals <- c("Day01", "Day02", "Day03", "Day04", "Day05",
                          "Day06", "Day07", "Day08", "Day09", "Day10",
                          "Day11", "Day12", "Day13", "Day14")
germination.indices(gcdata, total.seeds.col = "Total Seeds",
                    counts.intervals.cols = counts.per.intervals,
                    intervals = 1:14, partial = TRUE, max.int = 5)
```

```
   Genotype Rep Day01 Day02 Day03 Day04 Day05 Day06 Day07 Day08 Day09
1        G1   1     0     0     0     0     4    17    10     7     1
2        G2   1     0     0     0     1     3    15    13     6     2
3        G3   1     0     0     0     2     3    18     9     8     2
4        G4   1     0     0     0     0     4    19    12     6     2
5        G5   1     0     0     0     0     5    20    12     8     1
6        G1   2     0     0     0     0     3    21    11     7     1
7        G2   2     0     0     0     0     4    18    11     7     1
8        G3   2     0     0     0     1     3    14    12     6     2
9        G4   2     0     0     0     1     3    19    10     8     1
10       G5   2     0     0     0     0     4    18    13     6     2
11       G1   3     0     0     0     0     5    21    11     8     1
12       G2   3     0     0     0     0     3    20    10     7     1
13       G3   3     0     0     0     0     4    19    12     8     1
14       G4   3     0     0     0     0     3    21    11     6     1
15       G5   3     0     0     0     0     4    17    10     8     1
   Day10 Day11 Day12 Day13 Day14 Total Seeds GermPercent FirstGermTime
1      0     1     0     0     0           50    80.00000             5
2      1     0     1     0     0           51    82.35294             4
3      1     1     1     0     0           48    93.75000             4
4      1     1     1     0     0           51    90.19608             5
5      0     0     1     1     0           50    96.00000             5
6      1     1     1     0     0           49    93.87755             5
7      0     1     0     0     0           48    87.50000             5
8      1     0     1     0     0           47    85.10638             4
9      1     1     1     0     0           52    86.53846             4
10     1     0     1     0     0           50    90.00000             5
11     0     0     1     1     0           51    94.11765             5
12     1     1     1     0     0           51    86.27451             5
13     1     0     1     1     0           49    95.91837             5
14     0     1     1     0     0           48    91.66667             5
15     1     1     0     0     0           48    87.50000             5
   LastGermTime PeakGermTime TimeSpreadGerm t50_Coolbear t50_Farooq
1            11            6              6     5.970588   5.941176
2            12            6              8     6.192308   6.153846
3            12            6              8     6.000000   5.972222
4            12            6              7     6.041667   6.000000
5            13            6              8     5.975000   5.950000
6            12            6              7     5.976190   5.952381
```

```
7            11            6              6     5.972222   5.944444
8            12            6              8     6.208333   6.166667
9            12            6              8     6.000000   5.973684
10           12            6              7     6.076923   6.038462
11           13            6              8     5.928571   5.904762
12           12            6              7     5.975000   5.950000
13           13            6              8     6.083333   6.041667
14           12            6              7     5.928571   5.904762
15           11            6              6     6.050000   6.000000
   MeanGermTime VarGermTime SEGermTime CVGermTime MeanGermRate
1      6.700000    1.446154  0.1901416  0.1794868    0.1492537
2      6.857143    2.027875  0.2197333  0.2076717    0.1458333
3      6.866667    2.572727  0.2391061  0.2335882    0.1456311
4      6.891304    2.187923  0.2180907  0.2146419    0.1451104
5      6.812500    2.368351  0.2221275  0.2259002    0.1467890
6      6.869565    2.071498  0.2122088  0.2095140    0.1455696
7      6.690476    1.389663  0.1818989  0.1761967    0.1494662
8      6.875000    2.112179  0.2297923  0.2113940    0.1454545
9      6.866667    2.300000  0.2260777  0.2208604    0.1456311
10     6.822222    1.831313  0.2017321  0.1983606    0.1465798
11     6.791667    2.381206  0.2227295  0.2272072    0.1472393
12     6.886364    2.149577  0.2210295  0.2129053    0.1452145
13     6.936170    2.539315  0.2324392  0.2297410    0.1441718
14     6.772727    1.900634  0.2078370  0.2035568    0.1476510
15     6.809524    1.670151  0.1994129  0.1897847    0.1468531
    VarGermRate  SEGermRate      CVG GermRateRecip_Coolbear
1  0.0007176543 0.004235724 14.92537              0.1674877
2  0.0009172090 0.004673148 14.58333              0.1614907
3  0.0011572039 0.005071059 14.56311              0.1666667
4  0.0009701218 0.004592342 14.51104              0.1655172
5  0.0010995627 0.004786184 14.67890              0.1673640
6  0.0009301809 0.004496813 14.55696              0.1673307
7  0.0006935558 0.004063648 14.94662              0.1674419
8  0.0009454531 0.004861721 14.54545              0.1610738
9  0.0010345321 0.004794747 14.56311              0.1666667
10 0.0008453940 0.004334343 14.65798              0.1645570
11 0.0011191581 0.004828643 14.72393              0.1686747
12 0.0009558577 0.004660905 14.52145              0.1673640
13 0.0010970785 0.004831366 14.41718              0.1643836
14 0.0009033254 0.004531018 14.76510              0.1686747
15 0.0007767634 0.004300508 14.68531              0.1652893
   GermRateRecip_Farooq GermSpeed_Count GermSpeed_Percent
1             0.1683168        6.138925          12.27785
2             0.1625000        6.362698          12.47588
3             0.1674419        6.882179          14.33787
4             0.1666667        6.927417          13.58317
5             0.1680672        7.318987          14.63797
6             0.1680000        6.931782          14.14649
7             0.1682243        6.448449          13.43427
8             0.1621622        6.053175          12.87909
9             0.1674009        6.830592          13.13575
10            0.1656051        6.812698          13.62540
11            0.1693548        7.342796          14.39764
12            0.1680672        6.622258          12.98482
```

```
13            0.1655172        7.052320          14.39249
14            0.1693548        6.706782          13.97246
15            0.1666667        6.363925          13.25818
   GermSpeedAccumulated_Count GermSpeedAccumulated_Percent
1                    34.61567                     69.23134
2                    35.54058                     69.68741
3                    38.29725                     79.78594
4                    38.68453                     75.85202
5                    41.00786                     82.01571
6                    38.77620                     79.13509
7                    36.38546                     75.80304
8                    33.77079                     71.85275
9                    38.11511                     73.29829
10                   38.19527                     76.39054
11                   41.17452                     80.73436
12                   37.00640                     72.56158
13                   39.29399                     80.19182
14                   37.69490                     78.53103
15                   35.69697                     74.36868
   GermSpeedCorrected_Normal GermSpeedCorrected_Accumulated
1                 0.07673656                     0.4326958
2                 0.07726134                     0.4315642
3                 0.07340991                     0.4085040
4                 0.07680397                     0.4288937
5                 0.07623944                     0.4271652
6                 0.07383855                     0.4130508
7                 0.07369656                     0.4158338
8                 0.07112480                     0.3968068
9                 0.07893128                     0.4404413
10                0.07569665                     0.4243919
11                0.07801721                     0.4374793
12                0.07675799                     0.4289379
13                0.07352419                     0.4096608
14                0.07316490                     0.4112171
15                0.07273057                     0.4079653
   WeightGermPercent MeanGermPercent MeanGermNumber TimsonsIndex
1           47.42857        5.714286       2.857143     8.000000
2           47.89916        5.882353       3.000000     9.803922
3           54.46429        6.696429       3.214286    14.583333
4           52.24090        6.442577       3.285714     7.843137
5           56.14286        6.857143       3.428571    10.000000
6           54.51895        6.705539       3.285714     6.122449
7           51.93452        6.250000       3.000000     8.333333
8           49.39210        6.079027       2.857143    10.638298
9           50.27473        6.181319       3.214286     9.615385
10          52.57143        6.428571       3.214286     8.000000
11          55.18207        6.722689       3.428571     9.803922
12          50.00000        6.162465       3.142857     5.882353
13          55.24781        6.851312       3.357143     8.163265
14          53.86905        6.547619       3.142857     6.250000
15          51.19048        6.250000       3.000000     8.333333
   TimsonsIndex_Labouriau TimsonsIndex_KhanUngar GermRateGeorge PeakValue
1                    1.00              0.5714286              4  9.500000
2                    1.25              0.7002801              5  9.313725
```

```
3                   1.40             1.0416667             7 10.416667
4                   1.00             0.5602241             4 10.049020
5                   1.00             0.7142857             5 11.250000
6                   1.00             0.4373178             3 10.714286
7                   1.00             0.5952381             4 10.416667
8                   1.25             0.7598784             5  9.574468
9                   1.25             0.6868132             5  9.855769
10                  1.00             0.5714286             4 10.250000
11                  1.00             0.7002801             5 11.029412
12                  1.00             0.4201681             3  9.803922
13                  1.00             0.5830904             4 10.969388
14                  1.00             0.4464286             3 10.677083
15                  1.00             0.5952381             4 10.156250
   GermValue_Czabator GermValue_DP GermValue_Czabator_mod GermValue_DP_mod
1            54.28571     57.93890               54.28571         39.56076
2            54.78662     52.58713               54.78662         40.99260
3            69.75446     68.62289               69.75446         53.42809
4            64.74158     70.43331               64.74158         48.86825
5            77.14286     80.16914               77.14286         56.23935
6            71.84506     76.51983               71.84506         53.06435
7            65.10417     69.41325               65.10417         47.37690
8            58.20345     56.00669               58.20345         43.67948
9            60.92165     58.13477               60.92165         45.30801
10           65.89286     70.91875               65.89286         49.10820
11           74.14731     77.39782               74.14731         54.27520
12           60.41632     64.44988               60.41632         44.71582
13           75.15470     78.16335               75.15470         54.94192
14           69.90947     74.40140               69.90947         51.41913
15           63.47656     67.62031               63.47656         46.48043
      CUGerm GermSynchrony GermUncertainty
1  0.7092199     0.2666667        2.062987
2  0.5051546     0.2346109        2.321514
3  0.3975265     0.2242424        2.462012
4  0.4672113     0.2502415        2.279215
5  0.4312184     0.2606383        2.146051
6  0.4934701     0.2792271        2.160545
7  0.7371500     0.2729384        2.040796
8  0.4855842     0.2256410        2.357249
9  0.4446640     0.2494949        2.321080
10 0.5584666     0.2555556        2.187983
11 0.4288905     0.2686170        2.128670
12 0.4760266     0.2737844        2.185245
13 0.4023679     0.2506938        2.241181
14 0.5383760     0.2991543        2.037680
15 0.6133519     0.2497096        2.185028
```

Citing germinationmetrics

```
To cite the R package 'germinationmetrics' in publications use:

  Aravind, J., Vimala Devi, S., Radhamani, J., Jacob, S. R., and
  Kalyani Srinivasan (2019).  germinationmetrics: Seed Germination
  Indices and Curve Fitting. R package version 0.1.3,
```

```
  https://github.com/aravind-j/germinationmetricshttps://cran.r-project.org/package=germinationmetrics.

A BibTeX entry for LaTeX users is

  @Manual{,
    title = {germinationmetrics: Seed Germination Indices and Curve Fitting},
    author = {J. Aravind and S. {Vimala Devi} and J. Radhamani and Sherry Rachel Jacob and {Kalyani Srir
    year = {2019},
    note = {R package version 0.1.3},
    note = {https://github.com/aravind-j/germinationmetrics},
    note = {https://cran.r-project.org/package=germinationmetrics},
  }

This free and open-source software implements academic research by
the authors and co-workers. If you use it, please support the
project by citing the package.
```

Session Info

```
sessionInfo()
```

```
R Under development (unstable) (2018-10-27 r75507)
Platform: x86_64-w64-mingw32/x64 (64-bit)
Running under: Windows >= 8 x64 (build 9200)

Matrix products: default

locale:
[1] LC_COLLATE=English_India.1252  LC_CTYPE=English_India.1252
[3] LC_MONETARY=English_India.1252 LC_NUMERIC=C
[5] LC_TIME=English_India.1252

attached base packages:
[1] stats     graphics  grDevices utils     datasets  methods   base

other attached packages:
[1] germinationmetrics_0.1.3 readxl_1.2.0

loaded via a namespace (and not attached):
 [1] ggrepel_0.8.0       Rcpp_1.0.0          lattice_0.20-38
 [4] tidyr_0.8.2         prettyunits_1.0.2   ps_1.3.0
 [7] assertthat_0.2.0    rprojroot_1.3-2     digest_0.6.18
[10] R6_2.3.0            cellranger_1.1.0    plyr_1.8.4
[13] backports_1.1.3     evaluate_0.12       httr_1.4.0
[16] ggplot2_3.1.0       highr_0.7           pillar_1.3.1
[19] Rdpack_0.10-3       rlang_0.3.1         lazyeval_0.2.1
[22] curl_3.3            rstudioapi_0.9.0    data.table_1.12.0
[25] callr_3.1.1         rmarkdown_1.11      labeling_0.3
[28] desc_1.2.0          devtools_2.0.1.9000 pander_0.6.3
[31] stringr_1.3.1       RCurl_1.95-4.11     munsell_0.5.0
[34] broom_0.5.1         compiler_3.6.0      xfun_0.4
[37] pkgconfig_2.0.2     pkgbuild_1.0.2      htmltools_0.3.6
[40] tidyselect_0.2.5    tibble_2.0.1        roxygen2_6.1.1
[43] XML_3.98-1.16       crayon_1.3.4        dplyr_0.7.8
```

```
[46] withr_2.1.2         bitops_1.0-6        commonmark_1.7
[49] grid_3.6.0          nlme_3.1-137        gtable_0.2.0
[52] magrittr_1.5        scales_1.0.0        bibtex_0.4.2
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[58] remotes_2.0.2       bindrcpp_0.2.2      testthat_2.0.1
[61] xml2_1.2.0          generics_0.0.2      tools_3.6.0
[64] glue_1.3.0          purrr_0.2.5         processx_3.2.1
[67] pkgload_1.0.2       yaml_2.2.0          colorspace_1.4-0
[70] sessioninfo_1.1.1   gbRd_0.4-11         memoise_1.1.0
[73] minpack.lm_1.2-1    knitr_1.21          bindr_0.1.1
[76] usethis_1.4.0
```

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