# Package ‘isocalcR’

July 15, 2022

**Type** Package

**Title** Isotope Calculations in R

**Version** 0.1.0

**Author** Justin Mathias

**Date** 2022-07-14

**Maintainer** Justin Mathias <justin.m.mathias@gmail.com>

**Description** Perform common calculations based on published stable isotope theory, such as calculating carbon isotope discrimination and intrinsic water use efficiency from wood or leaf carbon isotope composition. See Farquhar, O'Leary, and Berry (1982) <doi:10.1071/PP9820121>.

**License** GPL-3

**URL** https://github.com/justinmathias/isocalcR

**BugReports** https://github.com/justinmathias/isocalcR/issues

**Depends** R (>= 4.0.0)

**Imports**

**Encoding** UTF-8

**Language** en-US

**LazyData** true

**Suggests** rmarkdown, knitr, testthat (>= 3.0.0), ggplot2, tidyr, dplyr

**VignetteBuilder** knitr

**Config/testthat/edition** 3

**RoxygenNote** 7.1.1

**NeedsCompilation** no

**Repository** CRAN

**Date/Publication** 2022-07-15 16:30:02 UTC

# R topics documented:



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`CO2data` *CO2data*

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## Description

Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Data are from Belmecheri, Lavergne, 2020, Dendrochronologia. Updated based on their methodology beyond C.E. 2019.

## Usage

```
data(CO2data)
```

## Format

A data frame with 2020 rows and 3 variables:

**yr** Year of CO2 and d13CO2 measurement

**Ca** Atmospheric CO2 concentration, in ppm

**d13C.atm** Atmospheric d13CO2, in per mille, %■

## Source

https://www.sciencedirect.com/science/article/abs/pii/S1125786520300874

## References

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

## Examples

```
data(CO2data)
head(CO2data)
```

custom.calc *custom.calc*

## Description

Calculates D13C, Ci, CiCa, diffCaCi, or iWUE with user specified values of d13C.plant, d13CO2.atm, atmospheric CO2, temperature, and elevation. The user can also specify whether to calculate each physiological index using the 'simple', 'photorespiration', or 'mesophyll' formulation in all calculations where Ci is computed. Method defaults to 'simple' assuming 'leaf' tissue and incorporates an apparent fractionation by Rubisco, b, of 27 permille (Cernusak and Ubierna 2022). If 'wood' tissue is supplied as an argument in the 'simple' method, the apparent fractionation by Rubisco, b, is updated to 25.5 permille (Cernusak and Ubierna 2022).

## Usage

```
custom.calc(
  d13C.plant,
  d13C.atm,
  frac = 0,
  outvar = "D13C",
  Ca = NULL,
  elevation = NULL,
  temp = NULL,
  method = "simple",
  tissue = "leaf"
)
```

## Arguments

| | |
|---|---|
| `d13C.plant` | Measured plant tissue carbon isotope signature, per mille (%■) |
| `d13C.atm` | Atmospheric d13CO2, per mille (%■) |
| `frac` | Post-photosynthetic fractionation factor, defaults to 0 assuming leaf material, user should supply reasonable value if from wood (generally -1.9 - -2.1) |
| `outvar` | Variable of interest to calculate from the following: D13C, Ci, CiCa, diffCaCi, or iWUE. Defaults to D13C. |
| `Ca` | Atmospheric CO2 concentration (ppm). |
| `elevation` | Elevation (m.a.s.l.) of the sample, necessary to account for photorespiration processes |
| `temp` | Leaf temperature (°C) |
| `method` | Method to calculate iWUE (simple, photorespiration, or mesophyll). Defaults to 'simple'. See Lavergne et al. 2022, Ma et al. 2021, Gong et al. 2022. |
| `tissue` | Plant tissue of the sample (i.e. leaf or wood) used only during calculations using the simple formulation. Defaults to 'leaf'. |

### Value

One of the specified outvars: D13C (permille), Ci (ppm), CiCa (unitless), diffCaCi (ppm), or iWUE (micromol CO2 per mol H2O). Defaults to 'D13C'.

### References

Badeck, F.-W., Tcherkez, G., Nogués, S., Piel, C. & Ghashghaie, J. (2005). Post-photosynthetic fractionation of stable carbon isotopes between plant organs—a widespread phenomenon. Rapid Commun. Mass Spectrom., 19, 1381–1391.

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

Bernacchi, C.J., Singsaas, E.L., Pimentel, C., Portis Jr, A.R. & Long, S.P. (2001). Improved temperature response functions for models of Rubisco-limited photosynthesis. Plant, Cell Environ., 24, 253–259.

Craig, H. (1953). The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53–92.

Cernusak, L. A. & Ubierna, N. Carbon Isotope Effects in Relation to CO2 Assimilation by Tree Canopies. in Stable Isotopes in Tree Rings: inferring physiological, climatic, and environmental responses 291–310 (2022). doi:10.1007/978-3-030-92698-4_9.

Davies, J.A. & Allen, C.D. (1973). Equilibrium, Potential and Actual Evaporation from Cropped Surfaces in Southern Ontario. J. Appl. Meteorol., 12, 649–657.

Farquhar, G., O'Leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol., 9, 121–137.

Frank, D.C., Poulter, B., Saurer, M., Esper, J., Huntingford, C., Helle, G., et al. (2015). Water-use efficiency and transpiration across European forests during the Anthropocene. Nat. Clim. Chang., 5, 579–583.

Gong, X. Y. et al. Overestimated gains in water-use efficiency by global forests. Glob. Chang. Biol. 1–12 (2022) doi:10.1111/gcb.16221.

Lavergne, A. et al. Global decadal variability of plant carbon isotope discrimination and its link to gross primary production. Glob. Chang. Biol. 28, 524–541 (2022).

Ma, W. T. et al. Accounting for mesophyll conductance substantially improves 13C-based estimates of intrinsic water-use efficiency. New Phytol. 229, 1326–1338 (2021).

Tsilingiris, P.T. (2008). Thermophysical and transport properties of humid air at temperature range between 0 and 100°C. Energy Convers. Manag., 49, 1098–1110.

Ubierna, N. & Farquhar, G.D. (2014). Advances in measurements and models of photosynthetic carbon isotope discrimination in C3 plants. Plant. Cell Environ., 37, 1494–1498.

### Examples

```
custom.calc(d13C.plant = -27, d13C.atm = -8.7)
```

`d13C.to.Ci` *d13C.to.Ci*

## Description

Calculates leaf intercellular CO2 concentration given plant tissue d13C signature. Defaults to the 'simple' formulation (See Lavergne et al. 2022) and 'leaf' tissue to calculate leaf Ci. Under the 'simple' formulation the apparent fractionation by Rubisco is 27 permille if from 'leaf' tissue and 25.5 permille if from wood tissue (Cernusak and Ubierna 2022).

## Usage

```
d13C.to.Ci(
  d13C.plant,
  year,
  elevation,
  temp,
  method = "simple",
  tissue = "leaf",
  frac = 0
)
```

## Arguments

| | |
|---|---|
| `d13C.plant` | Measured plant tissue carbon isotope signature, per mille (%■) |
| `year` | Year to which the sample corresponds |
| `elevation` | Elevation (m.a.s.l.) of the sample, necessary to account for photorespiration processes |
| `temp` | Leaf temperature (°C) |
| `method` | Method to calculate CiCa (simple, photorespiration, or mesophyll). See Lavergne et al. 2022, Ma et al. 2021, Gong et al. 2022 |
| `tissue` | Plant tissue of the sample (i.e. leaf or wood) used only during calculations using the simple formulation. Defaults to "leaf". |
| `frac` | Post-photosynthetic fractionation factor, defaults to 0 assuming leaf material, user should supply reasonable value if from wood (generally -1.9 - -2.1) |

## Value

The concentration of leaf internal CO2 (ppm)

## References

Badeck, F.-W., Tcherkez, G., Nogués, S., Piel, C. & Ghashghaie, J. (2005). Post-photosynthetic fractionation of stable carbon isotopes between plant organs—a widespread phenomenon. Rapid Commun. Mass Spectrom., 19, 1381–1391.

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

Bernacchi, C.J., Singsaas, E.L., Pimentel, C., Portis Jr, A.R. & Long, S.P. (2001). Improved temperature response functions for models of Rubisco-limited photosynthesis. Plant, Cell Environ., 24, 253–259.

Craig, H. (1953). The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53–92.

Cernusak, L. A. & Ubierna, N. Carbon Isotope Effects in Relation to CO2 Assimilation by Tree Canopies. in Stable Isotopes in Tree Rings: inferring physiological, climatic, and environmental responses 291–310 (2022). doi:10.1007/978-3-030-92698-4_9.

Davies, J.A. & Allen, C.D. (1973). Equilibrium, Potential and Actual Evaporation from Cropped Surfaces in Southern Ontario. J. Appl. Meteorol., 12, 649–657.

Farquhar, G., O'Leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol., 9, 121–137.

Frank, D.C., Poulter, B., Saurer, M., Esper, J., Huntingford, C., Helle, G., et al. (2015). Water-use efficiency and transpiration across European forests during the Anthropocene. Nat. Clim. Chang., 5, 579–583.

Gong, X. Y. et al. Overestimated gains in water-use efficiency by global forests. Glob. Chang. Biol. 1–12 (2022) doi:10.1111/gcb.16221.

Lavergne, A. et al. Global decadal variability of plant carbon isotope discrimination and its link to gross primary production. Glob. Chang. Biol. 28, 524–541 (2022).

Ma, W. T. et al. Accounting for mesophyll conductance substantially improves 13C-based estimates of intrinsic water-use efficiency. New Phytol. 229, 1326–1338 (2021).

Tsilingiris, P.T. (2008). Thermophysical and transport properties of humid air at temperature range between 0 and 100°C. Energy Convers. Manag., 49, 1098–1110.

Ubierna, N. & Farquhar, G.D. (2014). Advances in measurements and models of photosynthetic carbon isotope discrimination in C3 plants. Plant. Cell Environ., 37, 1494–1498.

## Examples

```
d13C.to.Ci(d13C.plant = -27,
                year = 2015,
                elevation = 900,
                temp = 24,
                method = "simple",
                tissue = "leaf")

d13C.to.Ci(d13C.plant = -27,
                year = 2015,
                elevation = 900,
                temp = 24,
                method = "simple",
                tissue = "wood")
```

```
d13C.to.Ci(d13C.plant = -27,
           year = 2015,
           elevation = 900,
           temp = 24,
           method = "photorespiration")
```

---

`d13C.to.CiCa` *d13C.to.CiCa*

---

## Description

Calculates the ratio of the concentration of leaf intercellular to atmospheric CO2, unitless. Defaults to the 'simple' formulation (See Lavergne et al. 2022) and 'leaf' tissue to calculate leaf Ci, and subsequently CiCa. Under the 'simple' formulation the apparent fractionation by Rubisco is 27 permille if from 'leaf' tissue and 25.5 permille if from wood tissue (Cernusak and Ubierna 2022).

## Usage

```
d13C.to.CiCa(
  d13C.plant,
  year,
  elevation,
  temp,
  method = "simple",
  tissue = "leaf",
  frac = 0
)
```

## Arguments

| | |
|---|---|
| `d13C.plant` | Measured plant tissue carbon isotope signature, per mille (%■) |
| `year` | Year to which the sample corresponds |
| `elevation` | Elevation (m.a.s.l.) of the sample, necessary to account for photorespiration processes |
| `temp` | Leaf temperature (°C) |
| `method` | Method to calculate CiCa (simple, photorespiration, or mesophyll). See Lavergne et al. 2022, Ma et al. 2021, Gong et al. 2022 |
| `tissue` | Plant tissue of the sample (i.e. leaf or wood) used only during calculations using the simple formulation. Defaults to "leaf". |
| `frac` | Post-photosynthetic fractionation factor, defaults to 0 assuming leaf material, user should supply reasonable value if from wood (generally -1.9 - -2.1) |

### Value

The ratio of leaf intercellular to atmospheric CO2 (Ci/Ca), unitless

### References

Badeck, F.-W., Tcherkez, G., Nogués, S., Piel, C. & Ghashghaie, J. (2005). Post-photosynthetic fractionation of stable carbon isotopes between plant organs—a widespread phenomenon. Rapid Commun. Mass Spectrom., 19, 1381–1391.

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

Bernacchi, C.J., Singsaas, E.L., Pimentel, C., Portis Jr, A.R. & Long, S.P. (2001). Improved temperature response functions for models of Rubisco-limited photosynthesis. Plant, Cell Environ., 24, 253–259.

Craig, H. (1953). The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53–92.

Cernusak, L. A. & Ubierna, N. Carbon Isotope Effects in Relation to CO2 Assimilation by Tree Canopies. in Stable Isotopes in Tree Rings: inferring physiological, climatic, and environmental responses 291–310 (2022). doi:10.1007/978-3-030-92698-4_9.

Davies, J.A. & Allen, C.D. (1973). Equilibrium, Potential and Actual Evaporation from Cropped Surfaces in Southern Ontario. J. Appl. Meteorol., 12, 649–657.

Farquhar, G., O'Leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol., 9, 121–137.

Frank, D.C., Poulter, B., Saurer, M., Esper, J., Huntingford, C., Helle, G., et al. (2015). Water-use efficiency and transpiration across European forests during the Anthropocene. Nat. Clim. Chang., 5, 579–583.

Gong, X. Y. et al. Overestimated gains in water-use efficiency by global forests. Glob. Chang. Biol. 1–12 (2022) doi:10.1111/gcb.16221.

Lavergne, A. et al. Global decadal variability of plant carbon isotope discrimination and its link to gross primary production. Glob. Chang. Biol. 28, 524–541 (2022).

Ma, W. T. et al. Accounting for mesophyll conductance substantially improves 13C-based estimates of intrinsic water-use efficiency. New Phytol. 229, 1326–1338 (2021).

Tsilingiris, P.T. (2008). Thermophysical and transport properties of humid air at temperature range between 0 and 100°C. Energy Convers. Manag., 49, 1098–1110.

Ubierna, N. & Farquhar, G.D. (2014). Advances in measurements and models of photosynthetic carbon isotope discrimination in C3 plants. Plant. Cell Environ., 37, 1494–1498.

### Examples

```
d13C.to.CiCa(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "simple",
```

```
tissue = "leaf")

d13C.to.CiCa(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "simple",
tissue = "wood")

d13C.to.CiCa(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "photorespiration")
```

---

`d13C.to.D13C` *d13C.to.D13C*

---

### Description

Calculates leaf carbon isotope discrimination given plant tissue d13C signature.

### Usage

```
d13C.to.D13C(d13C.plant, year, frac = 0)
```

### Arguments

| | |
|---|---|
| `d13C.plant` | Measured plant tissue carbon isotope signature, per mille (%■) |
| `year` | Year to which the sample corresponds |
| `frac` | Post-photosynthetic fractionation factor, defaults to 0 assuming leaf material with no post-photosynthetic fractionation. User should supply reasonable value if leaf fractionation present or if samples are from wood (generally -1.9 - -2.1). |

### Value

Carbon isotope discrimination in units of per mille (%■).

### References

Badeck, F.-W., Tcherkez, G., Nogués, S., Piel, C. & Ghashghaie, J. (2005). Post-photosynthetic fractionation of stable carbon isotopes between plant organs—a widespread phenomenon. Rapid Commun. Mass Spectrom., 19, 1381–1391.

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

Craig, H. (1953). The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53–92.

Cernusak, L. A. & Ubierna, N. Carbon Isotope Effects in Relation to CO2 Assimilation by Tree Canopies. in Stable Isotopes in Tree Rings: inferring physiological, climatic, and environmental responses 291–310 (2022). doi:10.1007/978-3-030-92698-4_9.

Farquhar, G., O'Leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol., 9, 121–137.

Frank, D.C., Poulter, B., Saurer, M., Esper, J., Huntingford, C., Helle, G., et al. (2015). Water-use efficiency and transpiration across European forests during the Anthropocene. Nat. Clim. Chang., 5, 579–583.

Ubierna, N. & Farquhar, G.D. (2014). Advances in measurements and models of photosynthetic carbon isotope discrimination in C3 plants. Plant. Cell Environ., 37, 1494–1498.

## Examples

```
d13C.to.D13C(d13C.plant = -27, year = 2015)
```

---

# d13C.to.diffCaCi *d13C.to.diffCaCi*

---

## Description

Calculates the difference between the atmospheric CO2 concentration and the leaf intercellular CO2 concentration in parts per mil (ppm). Defaults to the 'simple' formulation (See Lavergne et al. 2022) and 'leaf' tissue to calculate leaf Ci, and subsequently diffCaCi. Under the 'simple' formulation the apparent fractionation by Rubisco is 27 permille if from 'leaf' tissue and 25.5 permille if from wood tissue (Cernusak and Ubierna 2022).

## Usage

```
d13C.to.diffCaCi(
  d13C.plant,
  year,
  elevation,
  temp,
  method = "simple",
  tissue = "leaf",
  frac = 0
)
```

### Arguments

| | |
|---|---|
| `d13C.plant` | Measured plant tissue carbon isotope signature, per mille (%■) |
| `year` | Year to which the sample corresponds |
| `elevation` | Elevation (m.a.s.l.) of the sample, necessary to account for photorespiration processes |
| `temp` | Leaf temperature (°C) |
| `method` | Method to calculate CiCa (simple, photorespiration, or mesophyll). See Lavergne et al. 2022, Ma et al. 2021, Gong et al. 2022 |
| `tissue` | Plant tissue of the sample (i.e. leaf or wood) used only during calculations using the simple formulation. Defaults to "leaf". |
| `frac` | Post-photosynthetic fractionation factor, defaults to 0 assuming leaf material, user should supply reasonable value if from wood (generally -1.9 - -2.1) |

### Value

The difference between atmospheric and leaf intercellular CO2 concentrations (ppm).

### References

Badeck, F.-W., Tcherkez, G., Nogués, S., Piel, C. & Ghashghaie, J. (2005). Post-photosynthetic fractionation of stable carbon isotopes between plant organs—a widespread phenomenon. Rapid Commun. Mass Spectrom., 19, 1381–1391.

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

Bernacchi, C.J., Singsaas, E.L., Pimentel, C., Portis Jr, A.R. & Long, S.P. (2001). Improved temperature response functions for models of Rubisco-limited photosynthesis. Plant, Cell Environ., 24, 253–259.

Craig, H. (1953). The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53–92.

Cernusak, L. A. & Ubierna, N. Carbon Isotope Effects in Relation to CO2 Assimilation by Tree Canopies. in Stable Isotopes in Tree Rings: inferring physiological, climatic, and environmental responses 291–310 (2022). doi:10.1007/978-3-030-92698-4_9.

Davies, J.A. & Allen, C.D. (1973). Equilibrium, Potential and Actual Evaporation from Cropped Surfaces in Southern Ontario. J. Appl. Meteorol., 12, 649–657.

Farquhar, G., O'Leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol., 9, 121–137.

Frank, D.C., Poulter, B., Saurer, M., Esper, J., Huntingford, C., Helle, G., et al. (2015). Water-use efficiency and transpiration across European forests during the Anthropocene. Nat. Clim. Chang., 5, 579–583.

Gong, X. Y. et al. Overestimated gains in water-use efficiency by global forests. Glob. Chang. Biol. 1–12 (2022) doi:10.1111/gcb.16221.

Lavergne, A. et al. Global decadal variability of plant carbon isotope discrimination and its link to gross primary production. Glob. Chang. Biol. 28, 524–541 (2022).

Ma, W. T. et al. Accounting for mesophyll conductance substantially improves 13C-based estimates of intrinsic water-use efficiency. New Phytol. 229, 1326–1338 (2021).

Tsilingiris, P.T. (2008). Thermophysical and transport properties of humid air at temperature range between 0 and 100°C. Energy Convers. Manag., 49, 1098–1110.

Ubierna, N. & Farquhar, G.D. (2014). Advances in measurements and models of photosynthetic carbon isotope discrimination in C3 plants. Plant. Cell Environ., 37, 1494–1498.

## Examples

```
d13C.to.diffCaCi(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "simple",
tissue = "leaf")

d13C.to.diffCaCi(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "simple",
tissue = "wood")

d13C.to.diffCaCi(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "photorespiration")
```

---

# `d13C.to.iWUE` *d13C.to.iWUE*

---

## Description

Calculates leaf intrinsic water use efficiency given plant tissue d13C signature. Defaults to the 'simple' formulation (See Lavergne et al. 2022) and 'leaf' tissue to calculate leaf Ci, and subsequently iWUE. Under the 'simple' formulation the apparent fractionation by Rubisco is 27 permille if from 'leaf' tissue and 25.5 permille if from wood tissue (Cernusak and Ubierna 2022).

### Usage

```
d13C.to.iWUE(
  d13C.plant,
  year,
  elevation,
  temp,
  method = "simple",
  tissue = "leaf",
  frac = 0
)
```

### Arguments

| | |
|---|---|
| `d13C.plant` | Measured plant tissue carbon isotope signature, per mille (%■) |
| `year` | Year to which the sample corresponds |
| `elevation` | Elevation (m.a.s.l.) of the sample, necessary to account for photorespiration processes |
| `temp` | Leaf temperature (°C) |
| `method` | Method to calculate iWUE (simple, photorespiration, or mesophyll). See Lavergne et al. 2022, Ma et al. 2021, Gong et al. 2022 |
| `tissue` | Plant tissue of the sample (i.e. leaf or wood) used only during calculations using the simple formulation. Defaults to "leaf". |
| `frac` | Post-photosynthetic fractionation factor, defaults to 0 assuming leaf material, user should supply reasonable value if from wood (generally -1.9 - -2.1) |

### Value

Intrinsic water use efficiency in units of micromol CO2 per mol H2O.

### References

Badeck, F.-W., Tcherkez, G., Nogués, S., Piel, C. & Ghashghaie, J. (2005). Post-photosynthetic fractionation of stable carbon isotopes between plant organs—a widespread phenomenon. Rapid Commun. Mass Spectrom., 19, 1381–1391.

Belmecheri, S. & Lavergne, A. (2020). Compiled records of atmospheric CO2 concentrations and stable carbon isotopes to reconstruct climate and derive plant ecophysiological indices from tree rings. Dendrochronologia, 63, 125748.

Bernacchi, C.J., Singsaas, E.L., Pimentel, C., Portis Jr, A.R. & Long, S.P. (2001). Improved temperature response functions for models of Rubisco-limited photosynthesis. Plant, Cell Environ., 24, 253–259.

Craig, H. (1953). The geochemistry of the stable carbon isotopes. Geochim. Cosmochim. Acta, 3, 53–92.

Cernusak, L. A. & Ubierna, N. Carbon Isotope Effects in Relation to CO2 Assimilation by Tree Canopies. in Stable Isotopes in Tree Rings: inferring physiological, climatic, and environmental responses 291–310 (2022). doi:10.1007/978-3-030-92698-4_9.

Davies, J.A. & Allen, C.D. (1973). Equilibrium, Potential and Actual Evaporation from Cropped Surfaces in Southern Ontario. J. Appl. Meteorol., 12, 649–657.

Farquhar, G., O'Leary, M. & Berry, J. (1982). On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol., 9, 121–137.

Frank, D.C., Poulter, B., Saurer, M., Esper, J., Huntingford, C., Helle, G., et al. (2015). Water-use efficiency and transpiration across European forests during the Anthropocene. Nat. Clim. Chang., 5, 579–583.

Gong, X. Y. et al. Overestimated gains in water-use efficiency by global forests. Glob. Chang. Biol. 1–12 (2022) doi:10.1111/gcb.16221.

Lavergne, A. et al. Global decadal variability of plant carbon isotope discrimination and its link to gross primary production. Glob. Chang. Biol. 28, 524–541 (2022).

Ma, W. T. et al. Accounting for mesophyll conductance substantially improves 13C-based estimates of intrinsic water-use efficiency. New Phytol. 229, 1326–1338 (2021).

Tsilingiris, P.T. (2008). Thermophysical and transport properties of humid air at temperature range between 0 and 100°C. Energy Convers. Manag., 49, 1098–1110.

Ubierna, N. & Farquhar, G.D. (2014). Advances in measurements and models of photosynthetic carbon isotope discrimination in C3 plants. Plant. Cell Environ., 37, 1494–1498.


## Examples

```
d13C.to.iWUE(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "simple",
tissue = "leaf")

d13C.to.iWUE(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "simple",
tissue = "wood")

d13C.to.iWUE(d13C.plant = -27,
year = 2015,
elevation = 900,
temp = 24,
method = "photorespiration")
```

`piru13C` *piru13C*

### Description

Accompanying tree ring carbon isotope signature data for "Mathias, J.M. & Thomas, R.B. Disentangling the effects of acidic air pollution, atmospheric CO2, and climate change on recent growth of red spruce trees in the Central Appalachian Mountains. Glob. Chang. Biol. 24, 3938–3953 (2018).".

### Usage

```
data(piru13C)
```

### Format

A data frame with 223 rows and 6 variables:

**Year** Year of sample

**Site** Study location name

**wood.d13C** Measured tree ring (i.e. wood) d13C, in per mille, %■

**MGT_C** Mean growing season temperature, °C

**Elevation_m** Elevation of study location, meters

**frac** Leaf-to-wood fractionation factor

### Source

https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.14273

### References

Mathias, J.M. & Thomas, R.B. Disentangling the effects of acidic air pollution, atmospheric CO2, and climate change on recent growth of red spruce trees in the Central Appalachian Mountains. Glob. Chang. Biol. 24, 3938–3953 (2018).

### Examples

```
data(piru13C)
head(piru13C)
```

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