Package 'soilphysics'

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Description Basic and model-based soil physical analyses.

License GPL (>= 2)

NeedsCompilation no

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`soilphysics-package` *Soil Physical Analysis*

Description

Basic and model-based soil physical analyses.

Details

Package:	soilphysics
Type:	Package
Version:	3.1
Date:	2017-05-25
License:	GPL (>= 2)

Functions for modelling the load bearing capacity and the penetration resistance, and for predicting the stress applied by agricultural machines in the soil profile. The package allows one to model the soil water retention through six different models. There are some useful and easy-to-use functions to perform parameter estimation of these models. Methods to obtain the preconsolidation stress are available, such as the standard of Casagrande (1936) and so on. It is possible to quantify soil water availability for plants through the Least Limiting Water Range approach as well as the Integral Water Capacity. Moreover, it is possible to determine the water suction at the point of hydraulic cut-off. Also, users can deal with the high-energy-moisture-characteristics (HEMC) methodology proposed by Pierson & Mulla (1989), which is used to analyze the aggregate stability. There is a function to determine the soil critical moisture and the maximum bulk density for one or more samples, based on the Proctor (1933) compaction test. Other utilities like a function to calculate the soil liquid limit, the void ratio and to determine the maximum curvature point are available.

Note

soilphysics is an ongoing project. We welcome any and all criticism, comments and suggestions.

Author(s)

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Maintainer: Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

da Silva, A.R.; de Lima, R.P. (2015) soilphysics: an R package to determine soil preconsolidation pressure. *Computers and Geosciences*, 84: 54-60.

de Lima, R.P.; da Silva, A.R.; da Silva, A.P.; Leao, T.P.; Mosaddeghi, M.R. (2016) soilphysics: an R package for calculating soil water availability to plants by different soil physical indices. *Computers and Eletronics in Agriculture*, 120: 63-71.

da Silva, A.R.; Lima, R.P. (2017) Determination of maximum curvature point with the R package soilphysics. *International Journal of Current Research*, 9: 45241-45245.

`bulkDensity` *Soil Bulk Density Data Set*

Description

This data set refers to five observations of soil bulk density and soil moisture per sample. There are four soil samples.

Usage

```
data(bulkDensity)
```

Format

A data frame with 20 observations on the following 3 variables.

`Id` a factor with levels `s1` `s2` `s3` `s4`, the 'ID' of each soil sample.

`MOIS` a numeric vector containing soil moisture values (cm^3 / cm^3).

`BULK` a numeric vector containing soil bulk density values (g / cm^3).

Source

Simulated data.

Examples

```
data(bulkDensity)
summary(bulkDensity)
```

---

compaction *Soil Compaction Data Set*

Description

This data set refers to physical soil variables related to soil compaction.

Usage

```
data(compaction)
```

Format

A data frame with 50 observations on the following 4 variables.

`PR` a numeric vector containing soil penetration resistance values (MPa).

`BD` a numeric vector containing soil bulk density values (g / cm^3).

`Mois` a numeric vector containing soil moisture values (cm^3 / cm^3).

`PS` a numeric vector containing soil preconsolidation stress values (kPa).

Source

Simulated data.

Examples

```
data(compaction)
summary(compaction)
```

`criticalmoisture` *Critical Moisture and Maximum Bulk Density*

Description

Function to determine the soil Critical Moisture and the Maximum Bulk Density based on the Proctor (1933) compaction test. It estimates compaction curve by fitting a quadradtic regression model.

Usage

```
criticalmoisture(theta, Bd, samples = NULL, graph = TRUE, ...)

maxbulkdensity(theta, Bd, samples = NULL, graph = TRUE, ...)
```

Arguments

`theta`	a vector containing the soil moisture values.
`Bd`	a vector containing the the soil bulk density values.
`samples`	optional; a vector indicating the multiple samples. Default is NULL (one sample). See details.
`graph`	logical; if TRUE (default), the soil compaction curve is plotted.
`...`	further graphical arguments.

Details

If `samples` is ispecified, then it must has the same length of `theta` and `Bd`.

Value

An object of class 'criticalmoisture', i.e., a matrix containing the quadratic model coefficients (rows 1 to 3), the R-squared (row 4), the sample size (row 5), the critical soil moisture (row 6) and the maximum bulk density (row 7), per sample.

Note

`maxbulkdensity` is just an alias of `criticalmoisture`.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Proctor, E. R. (1933). Design and construction of rolled earth dams. *Eng. News Record*, 3: 245-284, 286-289, 348-351, 372-376.

Silva, A. P. et al. (2010). Indicadores da qualidade fisica do solo. In: Jong Van Lier, Q. (Ed). *Fisica do solo*. Vicosa (MG): Sociedade Brasileira de Ciencia do Solo. p.541-281.

See Also

maxcurv

Examples

```
# example 1 (1 sample)
mois <- c(0.083, 0.092, 0.108, 0.126, 0.135)
bulk <- c(1.86, 1.92, 1.95, 1.90, 1.87)
criticalmoisture(theta = mois, Bd = bulk)

# example 2 (4 samples)
data(bulkDensity)
attach(bulkDensity)
criticalmoisture(theta = MOIS, Bd = BULK, samples = Id)

# End (not run)
```

---

fitbusscher *Self-starting Nls Busscher's (1990) Model for Soil Penetration Resistance*

Description

Function to self start the nonlinear Busscher's (1990) model for penetration resistance, i.e., $Pr = b0 * (\theta^{b1}) * (Bd^{b2})$. It creates initial estimates (by log-linearization) of the parameters b0, b1 and b2 and uses them to provide its least-squares estimates through nls.

Usage

```
fitbusscher(Pr, theta, Bd, ...)
```

Arguments

Pr	a numeric vector containing penetration resistance values.
theta	a numeric vector containing soil moisture values at which to evaluate the model.
Bd	a numeric vector containing bulk density values at which to evaluate the model.
...	further arguments to nls.

Value

A nls output (see help(nls)).

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Busscher, W. J. (1990). Adjustment of flat-tipped penetrometer resistance data to common water content. *Transactions of the ASAE*, 3:519-524.

See Also

fitlbc, nls, summary.nls, predict.nls, Rsq

Examples

```
data(compaction)
attach(compaction)
out <- fitbusscher(Pr = PR, theta = Mois, Bd = BD)
summary(out)
Rsq(out)

# 3D plot
X <- seq(min(Mois), max(Mois), len = 30) # theta
Y <- seq(min(BD), max(BD), len = 30) # Bd
f <- function(x, y) coef(out)[1] * (x^coef(out)[2]) * (y^coef(out)[3])
Z <- outer(X, Y, f)
persp(X, Y, Z,
xlab = "Soil moisture",
ylab = "Soil bulk density",
zlab = "Penetration resistance",
ticktype = "detailed",
phi = 20, theta = 30)

# End (not run)
```

---

fitlbc	*Parameter Estimation of the Load Bearing Capacity Model*

Description

This function creates initial parameter estimates of the nonlinear Load Bearing Capacity (Dias Jr., 1994) model, i.e., $\sigma_P = 10^{(b0+b1*\theta)}$, by using two methods: a getInitial method or a log-linearization. Then, it uses them to provide its least-squares estimates via nls.

Usage

```
fitlbc(theta, sigmaP, ...)
```

Arguments

theta	a numeric vector containing soil moisture values.
sigmaP	a numeric vector containing values of soil preconsolidation stress.
...	further arguments to nls.

Value

A nls object.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dias Junior, M. S. (1994). *Compression of three soils under longterm tillage and wheel traffic*. 1994. 114p. Ph.D. Thesis - Michigan State University, East Lansing.

See Also

sigmaP, fitbusscher, maxcurv, Rsq

Examples

```
data(compaction)
attach(compaction)
out <- fitlbc(theta = Mois, sigmaP = PS)
summary(out)
Rsq(out)
curve(10^(coef(out)[1] + coef(out)[2]*x))

# End (not run)
```

---

fitsoilwater *Interactive Estimation of van Genuchten's (1980) Model Parameters*

Description

An interactive graphical adjustment of the soil water retention curve via van Genuchten's (1980) formula. The nonlinear least-squares estimates can be achieved taking the graphical initial values.

Usage

```
fitsoilwater(theta, x, xlab = NULL, ylab = NULL, ...)
```

Arguments

theta	a numeric vector containing the values of soil water content.
x	a numeric vector containing the matric potential values.
xlab	a label for the x axis; if is NULL, the label "Matric potential" is used.
ylab	a label for the y axis; if is NULL, the label "Soil water content" is used.
...	further graphical arguments; see par.

Value

A plot of `theta` versus `x` and the curve of the current fitted model according to the adjusted parameters in an external interactive panel. Pressing the button "NLS estimates" a `nls` summary of the fitted model is printed on console whether convergence is achieved, otherwise a warning box of "No convergence" is shown.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Genuchten, M. T. van. (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal*, 44:892-898.

See Also

`nls`, `soilwater`

Examples

```
# Liu et al. (2011)
h <- c(0.001, 50.65, 293.77, 790.14, 992.74, 5065, 10130, 15195)
w <- c(0.5650, 0.4013, 0.2502, 0.2324, 0.2307, 0.1926, 0.1812, 0.1730)
fitsoilwater(w, h)

# End (not run)
```

`fitsoilwater2` *Interactive Estimation of the Groenevelt and Grant (2004) Model Parameters*

Description

An interactive graphical adjustment of the soil water retention curve via Groenevelt and Grant (2004) formula. The nonlinear least-squares estimates can be achieved taking the graphical initial values.

Usage

```
fitsoilwater2(theta, x, x0 = 6.653, xlab = NULL, ylab = NULL, ...)
```

Arguments

`theta`	a numeric vector containing the values of soil water content.
`x`	a numeric vector containing pF (pore water suction) values. See `soilwater2`.
`x0`	the value of pF at which the soil water content becomes zero. The default is 6.653.
`xlab`	a label for the x axis; if is NULL, the label "pF" is used.
`ylab`	a label for the y axis; if is NULL, the label "Soil water content" is used.
`...`	further graphical arguments; see `par`.

Value

A plot of `theta` versus `x` and the curve of the current fitted model according to the adjusted parameters in an external interactive panel. Pressing the button "NLS estimates" a `nls` summary of the fitted model is printed on console whether convergence is achieved, otherwise a warning box of "No convergence" is shown.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Groenevelt & Grant (2004). A newmodel for the soil-water retention curve that solves the problem of residualwater contents. *European Journal of Soil Science*, 55:479-485.

See Also

`nls`, `soilwater2`, `soilwater`

Examples

```
w <- c(0.417, 0.354, 0.117, 0.048, 0.029, 0.017, 0.007, 0)
pF <- 0:7
fitsoilwater2(w, pF)

# End (not run)
```

`fitsoilwater3` *Interactive Estimation of the Dexter's (2008) Model Parameters*

Description

An interactive graphical adjustment of the soil water retention curve through the Dexter's (2008) formula. The nonlinear least-squares estimates can be achieved taking the graphical initial values.

Usage

```
fitsoilwater3(theta, x, xlab = NULL, ylab = NULL, ...)
```

Arguments

theta	a numeric vector containing the values of soil water content.
x	a numeric vector containing the values of applied air pressure.
xlab	a label for the x axis; if is NULL, the label "pF" is used.
ylab	a label for the y axis; if is NULL, the label "Soil water content" is used.
...	further graphical arguments; see par.

Value

A plot of theta versus x and the curve of the current fitted model according to the adjusted parameters in an external interactive panel. Pressing the button "NLS estimates" a nls summary of the fitted model is printed on console whether convergence is achieved, otherwise a warning box of "No convergence" is shown.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dexter et al. (2008). A user-friendly water retention function that takes account of the textural and structural pore spaces in soil. *Geoderma*, 143:243–253.

See Also

soilwater3, nls, fitsoilwater2

Examples

```
# data extracted from Liu et al. (2011)
h <- c(0.001, 50.65, 293.77, 790.14, 992.74, 5065, 10130, 15195)
w <- c(0.5650, 0.4013, 0.2502, 0.2324, 0.2307, 0.1926, 0.1812, 0.1730)
fitsoilwater3(w, h)

# End (not run)
```

fitsoilwater4 *Self-starting Nls Power Models for Soil Water Retention*

Description

Function to self start the following nonlinear power models for soil water retention:

$$\theta = \exp(a + b * Bd)\psi^c$$

(Silva et al., 1994)

$$\theta = a\psi^c$$

(Ross et al., 1991)

where θ is the soil water content.

`fitsoilwater()` creates initial estimates (by log-linearization) of the parameters a, b and c and uses them to provide its least-squares estimates through `nls`.

Usage

```
fitsoilwater4(theta, psi, Bd, model = c("Silva", "Ross"))
```

Arguments

`theta`	a numeric vector containing values of soil water content.
`psi`	a numeric vector containing values of water potential (Psi).
`Bd`	a numeric vector containing values of dry bulk density.
`model`	a character; the model to be used for calculating the soil water content. It must be one of the two: `"Silva"` (default) or `"Ross"`.

Value

A "nls" object containing the fitted model.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Ross et al. (1991). Equation for extending water-retention curves to dryness. *Soil Science Society of America Journal*, 55:923-927.

Silva et al. (1994). Characterization of the least limiting water range of soils. *Soil Science Society of America Journal*, 58:1775-1781.

See Also

fitsoilwater4, soilwater, soilwater2, soilwater3

Examples

```
# Example 1
ex1 <- with(skp1994,
    fitsoilwater4(theta = W, psi = h, model = "Ross"))
ex1
summary(ex1)

# Example 2
ex2 <- with(skp1994,
    fitsoilwater4(theta = W, psi = h, Bd = BD, model = "Silva"))
ex2
summary(ex2)

# Not run
```

---

fitsoilwater5 *Interactive Estimation of the Modified van Genuchten's Model Parameters*

Description

An interactive graphical adjustment of the soil water retention curve via the van Genuchten's formula, modified by Pierson and Mulla (1989). The nonlinear least-squares estimates can be achieved taking the graphical initial values. It may be useful to estimate the parameters needed in the high-energy-moisture-characteristics (HEMC) method, which is used to analyze the aggregate stability.

Usage

```
fitsoilwater5(theta, x, theta_S, xlab = NULL, ylab = NULL, ...)
```

Arguments

`theta`	a numeric vector containing the values of soil water content.
`x`	a numeric vector containing the matric potential values.
`theta_S`	an offset; a value for the parameter `theta_S`, the water content at saturation. See details.
`xlab`	a label for the x axis; if is NULL, the label "Matric potential" is used.
`ylab`	a label for the y axis; if is NULL, the label "Soil water content" is used.
`...`	further graphical arguments; see par.

Details

The parameter theta_S must be passed as an argument. It is recommended to consider it as the highest water content value in the data set or the water content at saturation.

Value

A plot of `theta` versus `x` and the curve of the current fitted model according to the adjusted parameters in an external interactive panel. Pressing the button "NLS estimates" a `nls` summary of the fitted model is printed on console whether convergence is achieved, otherwise a warning box of "No convergence" is shown.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Pierson, F.B.; Mulla, D.J. (1989) An Improved Method for Measuring Aggregate Stability of a Weakly Aggregated Loessial Soil. *Soil Sci. Soc. Am. J.*, 53:1825–1831.

See Also

`nls`, `soilwater5`

Examples

```
h <- seq(0.1, 40, by = 2)
w <- c(0.735, 0.668, 0.635, 0.612, 0.559, 0.462, 0.369, 0.319, 0.296, 0.282,
0.269, 0.256, 0.249, 0.246, 0.239, 0.236, 0.229, 0.229, 0.226, 0.222)
plot(w ~ h)

# suggestions of starting values: thetaR = 0.35, alpha = 0.1, n = 10,
# b0 = 0.02, b1 = -0.0057, b2 = 0.00004 (Not run)

fitsoilwater5(theta = w, x = h, theta_S = 0.70)

# End (Not run)
```

---

fun2form *Converting Function to Formula*

Description

An accessorial function to convert an object of `class` 'function' to an object of `class` 'formula'.

Usage

```
fun2form(fun, y = NULL)
```

Arguments

`fun`	a object of class 'function'. It must be a one-line-written function, with no curly braces "{}".
`y`	optional; a character defining the lef side of the formula, `y = fun()`.

Value

An object of class formula.

Warning

Numerical values into fun with three or more digits may cause miscalculation.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

See Also

function, formula

Examples

```
g <- function(x) Asym * exp(-b2 * b3 ^ x) # Gompertz Growth Model
fun2form(g, "y")

# f1 <- function(w) {exp(w)} # error
# fun2form(f1, "x")
f2 <- function(w) exp(w) # ok
fun2form(f2, "x")

# End (not run)
```

---

getInitiallbc — *Get Initial Parameter Estimates for the Load Bearing Capacity Model*

Description

This is a getInitial function that evaluates initial parameter estimates for the Load Bearing Capacity model via SSlbc.

Usage

```
getInitiallbc(theta, sigmaP)
```

Arguments

theta	a numeric vector containing values of soil moisture.
sigmaP	a numeric vector containing values of preconsolidation stress.

Value

A numeric vector containing the estimates of the parameters b0 and b1.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dias Junior, M. S. (1994). *Compression of three soils under longterm tillage and wheel traffic*. 1994. 114p. Ph.D. Thesis - Michigan State University, East Lansing.

See Also

getInitial, SSlbc, nls, sigmaP

Examples

```
data(compaction)
attach(compaction)
getInitiallbc(theta = Mois, sigmaP = PS)

# End (not run)
```

---

hemc *High-Energy-Moisture-Characteristics Aggregate Stability*

Description

A function to determine the modal suction, volume of drainable pores, structural index and stability ratio using the high-energy-moisture-characteristics (HEMC) method by Pierson & Mulla (1989), which is used to analyze the aggregate stability. Before using `hemc()`, the user may estimate the parameters of the Modified van Genuchten's Model through the function `fitsoilwater5()`.

Usage

```
hemc(x, theta_R, theta_S, alpha, n, b1, b2,
graph = TRUE, from = 1, to = 30,
xlab = expression(Psi ~ (J~kg^{-1})),
ylab = expression(d ~ theta/d ~ Psi), ...)
```

Arguments

`x`	a vector containing matric potential values.
`theta_R`	a numeric vector of length two containing the parameter values in the following orde: fast and slow.
`theta_S`	a numeric vector of length two containing the parameter values in the following orde: fast and slow.
`alpha`	a numeric vector of length two containing the parameter values in the following orde: fast and slow.

n	a numeric vector of length two containing the parameter values in the following orde: fast and slow.
b1	a numeric vector of length two containing the parameter values in the following orde: fast and slow.
b2	a numeric vector of length two containing the parameter values in the following orde: fast and slow.
graph	logical; if TRUE (default), a graphical solution is shown).
from	the lower limit for the x-axis
to	the lower limit for the x-axis
xlab	a label for the x-axis
ylab	a label for the y-axis
...	further graphical arguments

Value

A list of a two objects: 1) a matrix containing the Modal Suction, the Volume od Drainable Pores (VDP) and the Structural Index for both, fast and slow wetting; and 2) the value of Stability Ratio.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Pierson, F.B.; Mulla, D.J. (1989). An Improved Method for Measuring Aggregate Stability of a Weakly Aggregated Loessial Soil. *Soil Sci. Soc. Am. J.*, 53:1825–1831.

See Also

fitsoilwater5

Examples

```
hemc(x = seq(1, 30), theta_R = c(0.27, 0.4), theta_S = c(0.65, 0.47),
alpha = c(0.1393, 0.0954), n = c(6.37, 7.47),
b1 = c(-0.008421, -0.011970), b2 = c(0.0001322, 0.0001552))

# End (Not run)
```

hydraulicCutOff *Pore Water Suction at the Point of Hydraulic Cut-Off*

Description

The pore water suction at the point of hydraulic cut-off occurs at the point where the residual water content, obtained from Dexter et al. (2008), intercepts with the Groenevelt & Grant (2004) retention curve.

Usage

```
hydraulicCutOff(theta_R, k0, k1, n, x0 = 6.653)
```

Arguments

theta_R	a parameter that represents the residual water content at the the Dexter's (2008) Water Retention Model.
k0	a parameter value, extracted from the water retention curve based on the Groenevelt & Grant (2004) formula.
k1	a parameter value, extracted from the water retention curve based on the Groenevelt & Grant (2004) formula.
n	a parameter value, extracted from the water retention curve based on the Groenevelt & Grant (2004) formula.
x0	the value of pF (pore water suction) at which the soil water content becomes zero. The default is 6.653.

Value

The water suction at the point of hydraulic cut-off.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dexter, A.R.; Czyz, E.A.; Richard, G.; Reszkowska, A. (2008). A user-friendly water retention function that takes account of the textural and structural pore spaces in soil. *Geoderma*, 143:243–253.

Groenevelt, P.H.; Grnat, C.D. (2004). A new model for the soil-water retention curve that solves the problem of residual water contents. *European Journal of Soil Science*, 55:479–485.

See Also

fitsoilwater2, fitsoilwater3

Examples

```
# Dexter et al. (2012), Table 4A
hydraulicCutOff(0.1130, 6.877, 0.6508, 1.0453)
hydraulicCutOff(0.1122, 12.048, 0.4338, 2.0658)

# End (not run)
```

---

iwc *Integral Water Capacity (IWC)*

Description

Quantifying the soil water availability for plants through the IWC approach. The theory was based on the work of Groenevelt et al. (2001), Groenevelt et al. (2004) and Asgarzadeh et al. (2014), using the van Genuchten-Mualem Model for estimation of the water retention curve and a simple power model for penetration resistance. The salinity effect on soil available water is also implemented here, according to Groenevelt et al. (2004).

Usage

```
iwc(theta_R, theta_S, alpha, n, a, b, hos = 0,
    graph = TRUE,
    xlab = "Matric head (cm)",
    ylab = expression(cm^-1),
    xlim1 = NULL,
    xlim2 = NULL,
    xlim3 = NULL,
    ylim1 = NULL,
    ylim2 = NULL,
    ylim3 = NULL,
    col12 = c("black", "blue", "red"),
    col3 = c("orange", "black"),
    lty12 = c(1, 3, 2),
    lty3 = c(2, 1), ...)
```

Arguments

theta_R	the residual water content ($m^3\ m{-}3$); a numeric parameter from van Genuchten's model; see details.
theta_S	the water content at saturation ($m^3\ m{-}3$); a numeric parameter from van Genuchten's model; see details.
alpha	a scale parameter from van Genuchten's model; see details.
n	a shape parameter from van Genuchten's model; see details.
a	a parameter of the soil penetration resistance model; see details.
b	a parameter of the soil penetration resistance model; see details.

hos	optional; the value of osmotic head of the saturated soil extract (cm). Used only if one is concerned about the salinity effects on the water available for plants. Default is zero. See Groenevelt et al. (2004) for more details.
graph	logical; if TRUE (default), graphics for both dry and wet range are built.
xlab	a label for x-axis.
ylab	a label for y-axis.
xlim1, xlim2, xlim3	the x limits (x1, x2) of each plot. See plot.default.
ylim1, ylim2, ylim3	the y limits (y1, y2) of each plot. See plot.default.
col12	a vector of length 3 containing the color of each line of the first two plots. See par.
col3	a vector of length 2 containing the color of each line of the third plot. See par.
lty12	a vector of length 3 containing the line types for the first two plots. See par.
lty3	a vector of length 2 containing the line types for the third plot. See par.
...	further graphical parameters. See par.

Details

The parameters of the van Genuchten-Mualem Model can be estimated through the function `fitsoilwater()`. The soil penetration resistance model is given by: $PR = a * h^b$, where h is the soil water content and a and b are the fitting parameters.

Value

A table containing each integration of IWC (integral water capacity, in m/m) and EI (integral energy calculation, in J/kg).

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Asgarzadeh, H.; Mosaddeghi, M.R.; Nikbakht, A.M. (2014) SAWCal: A user-friendly program for calculating soil available water quantities and physical quality indices. *Computers and Electronics in Agriculture*, 109:86–93.

Groenevelt, P.H.; Grant, C.D.; Semetsa, S. (2001) A new procedure to determine soil water availability. *Australian Journal Soil Research*, 39:577–598.

Groenevelt, P.H., Grant, C.D., Murray, R.S. (2004) On water availability in saline soils. *Australian Journal Soil Research*, 42:833–840.

See Also

soilwater, fitsoilwater, llwr

Examples

```
# example 1 (Fig 1b, Asgarzadeh et al., 2014)
iwc(theta_R = 0.0160, theta_S = 0.4828, alpha = 0.0471, n = 1.2982,
a = 0.2038, b = 0.2558, graph = TRUE)

# example 2 (Table 1, Asgarzadeh et al., 2014)
iwc(theta_R = 0.166, theta_S = 0.569, alpha = 0.029, n = 1.308,
a = 0.203, b = 0.256, graph = TRUE)

# example 3: evaluating the salinity effect
iwc(theta_R = 0.166, theta_S = 0.569, alpha = 0.029, n = 1.308,
a = 0.203, b = 0.256, hos = 200, graph = TRUE)

# End (Not run)
```

`liquidlimit` *Soil Liquid Limit*

Description

Function to determine the soil Liquid Limit by using the Sowers (1965) method.

$$LL = \theta * (n/25)^{0.12}$$

.

Usage

```
liquidlimit(theta, n)
```

Arguments

`theta`	the soil mositure value corresponding to `n` drops.
`n`	the number of drops.

Value

The soil moisture value corresponding to the Liquid Limit.

Author(s)

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References

Sowers, G. F. (1965). Consistency. In: BLACK, C.A. (Ed.). *Methods of soil analysis*. Madison: American Society of Agronomy. Part 1, p.391-399. (Agronomy, 9).

Sowers, G. F. (1965). Consistency. In: KLUTE, A. (Ed.). 2 ed. *Methods of soil analysis*. Madison: American Society of Agronomy. Part 1, p.545-566.

See Also

criticalmoisture

Examples

```
liquidlimit(theta = 0.34, n = 22)

M <- c(0.34, 0.29, 0.27, 0.25, 0.20)
N <- c(22, 24, 25, 26, 28)
liquidlimit(theta = M, n = N)

# End (not run)
```

---

llwr — *Least Limiting Water Range (LLWR)*

Description

Graphical solution for the Least Limiting Water Range and parameter estimation of the related water retention and penetration resistance curves. A summary containing standard errors and statistical significance of the parameters is also given.

Usage

```
llwr(theta, h, Bd, Pr,
    particle.density, air,
    critical.PR, h.FC, h.WP,
    water.model = c("Silva", "Ross"),
    Pr.model = c("Busscher", "noBd"),
    pars.water = NULL, pars.Pr = NULL,
    graph = TRUE, graph2 = TRUE,
    xlab = expression(Bulk~Density~(Mg~m^{-3})),
    ylab = expression(theta~(m^{3}~m^{-3})),
    main = "Least Limiting Water Range", ...)
```

Arguments

`theta`	a numeric vector containing values of volumetric water content ($m^3\ m^{-3}$).
`h`	a numeric vector containing values of matric head (cm, Psi, MPa, kPa, ...).
`Bd`	a numeric vector containing values of dry bulk density ($Mg\ m^{-3}$). Note that `Bd` can also be a vector of length 1. See details.
`Pr`	a numeric vector containing values of penetration resistance (MPa, kPa, ...).
`particle.density`	the value of the soil particle density ($Mg\ m^{-3}$).
`air`	the value of the limiting volumetric air content ($m^3\ m^{-3}$).
`critical.PR`	the value of the critical soil penetration resistance.

`h.FC`	the value of matric head at the field capacity (cm, MPa, kPa, hPa, ...).
`h.WP`	the value of matric head at the wilting point (cm, MPa, kPa, hPa, ...).
`water.model`	a character; the model to be used for calculating the soil water content. It must be one of the two: `"Silva"` (default) or `"Ross"`. See details.
`Pr.model`	a character; the model to be used to predict soil penetration resistance. It must be one of the two: `"Busscher"` (default) or `"noBd"`. See details.
`pars.water`	optional; a numeric vector containing the estimates of the three parameters of the soil water retention model employed. If `NULL` (default), `llwr()` estimates them using a Newton-Raphson algorithm. See details.
`pars.Pr`	optional; a numeric vector containing estimates of the three parameters of the model proposed by Busscher (1990) for the functional relationship among `Pr`, `theta` and `Bd`. If NULL (default), `llwr()` estimates them using a Newton-Raphson algorithm. Moreover, if `Pr.model = "noBd"`, then the third value is considered to be null.
`graph`	logical; if TRUE (default) a graphical solution for the Least Limiting Water Range is plotted.
`graph2`	logical; if TRUE (default) a line of the Least Limiting Water Range as a function of bulk density is plotted. If `graph = FALSE`, then `llwr()` will automatically consider `graph2 = FALSE` too.
`xlab`	a title for the x axis; the default is $Bulk\ Density\ (Mg\ m^{-3})$.
`ylab`	a title for the y axis; the default is $\theta\ (m^3\ m^{-3})$.
`main`	a main title for the graphic; the default is "Least Limiting Water Range"
`...`	further graphical arguments.

Details

The numeric vectors `theta`, `h`, `Bd` and `Pr` are supposed to have the same length, and their values should have appropriate unit of measurement. For fitting purposes, it is not advisable to use vectors with less than five values. It is possible to calculate the LLWR for a especific (unique) value of bulk density. In This case, `Bd` should be a vector of length 1 and, therfore, it is not possible to fit the models `"Silva"` and `"Busscher"`, for water content and penetration resistance, respectively.

The model employed by Silva et al. (1994) for the soil water content (θ) as a function of the soil bulk density (ρ) and the matric head (h) is:

$$\theta = exp(a + b\rho)h^c$$

The model proposed by Ross et al. (1991) for the soil water content (θ) as a function of the matric head (h) is:

$$\theta = ah^c$$

The penetration resistance model, as presented by Busscher (1990), is given by

$$Pr = b0 * (\theta^{b1}) * (\rho^{b2})$$

If the agrument Bd receives a single value of bulk density, then llwr() fits the following simplified model (option noBd):

$$Pr = b0 * \theta^{b1}$$

Value

A list of

limiting.theta
: a $nx4$ matrix containing the limiting values of water content for each input value of bulk density at the volumetric air content (thetaA), penetration resistance (thetaPR), field capacity (thetaFC) and wilting point (thetaWP).

pars.water
: a "nls" object or a numeric vector containing estimates of the three parameters of the model employed by Silva et al. (1994) for the functional relationship among theta, Bd and h.

r.squared.water
: a "Rsq" object containing the pseudo and the adjusted R-squared for the water model.

pars.Pr
: a "nls" object or a numeric vector containing estimates of the three parameters of the penetration resistance model.

r.squared.Pr
: a "Rsq" object containing the pseudo and the adjusted R-squared for the penetration resistance model.

area
: numeric; the value of the shaded (LLWR) area. Calculated only when Bd is a vector of length > 1.

LLWR
: numeric; the value of LLWR ($m^3\ m^{-3}$) corresponding to Bd. Calculated only when Bd is a single value.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Busscher, W. J. (1990). Adjustment of flat-tipped penetrometer resistance data to common water content. *Transactions of the ASAE*, 3:519-524.

Leao et al. (2005). An Algorithm for Calculating the Least Limiting Water Range of Soils. *Agronomy Journal*, 97:1210-1215.

Leao et al. (2006). Least limiting water range: A potential indicator of changes in near-surface soil physical quality after the conversion of Brazilian Savanna into pasture. *Soil & Tillage Research*, 88:279-285.

Ross et al. (1991). Equation for extending water-retention curves to dryness. *Soil Science Society of America Journal*, 55:923-927.

Silva et al. (1994). Characterization of the least limiting water range of soils. *Soil Science Society of America Journal*, 58:1775-1781.

See Also

fitbusscher

Examples

```
# Example 1 - part of the data set used by Leao et al. (2005)
data(skp1994)
ex1 <- with(skp1994,
llwr(theta = W, h = h, Bd = BD, Pr = PR,
particle.density = 2.65, air = 0.1,
critical.PR = 2, h.FC = 100, h.WP = 15000))
ex1

# Example 2 - specifying the parameters (Leao et al., 2005)
a <- c(-0.9175, -0.3027, -0.0835)  # Silva et al. model of water content
b <- c(0.0827, -1.6087, 3.0570)   # Busscher's model
ex2 <- with(skp1994,
llwr(theta = W, h = h, Bd = BD, Pr = PR,
particle.density = 2.65, air = 0.1,
critical.PR = 2, h.FC = 100, h.WP = 15000,
pars.water = a, pars.busscher = b))
ex2

# Example 3 - specifying a single value for Bd
ex3 <- with(skp1994,
llwr(theta = W, h = h, Bd = 1.45, Pr = PR,
particle.density = 2.65, air = 0.1,
critical.PR = 2, h.FC = 100, h.WP = 15000))
ex3

# End (not run)
```

---

llwrPTF *Least Limiting Water Range (LLWR) Using Pedo-Transfer Functions*

Description

It calculates Least Limiting Water Range (LLWR) using pedo-transfer functions in according to Silva \& Kay (1997) and Silva et al. (2008), for Canadian and Brazilian soils, respectively.

Usage

```
llwrPTF(air, critical.PR, h.FC, h.WP, p.density, Bd, clay.content, org.carbon = NULL)
```

Arguments

air	the value of the limiting volumetric air content, m^3m^{-3}
critical.PR	the value of the critical soil penetration resistance, MPa
h.FC	the value of matric suction at the field capacity, hPa
h.WP	the value of matric suction at the wilting point, hPa
p.density	the value of the soil particle density, Mgm^{-3}
Bd	a numeric vector containing values of dry bulk density, Mgm^{-3}. Note that Bd can also be a vector of length 1.
clay.content	a numeric vector containing values of clay content to each bulk density, $\%$
org.carbon	a numeric vector containing values of organic carbon to each bulk density, $\%$, for Canadian soils. Default is 2%. See details.

Details

Note that org.carbon is only required for Canadian soil. If it is not passed, LLWR for Canadian soil is calculated with 2% of organic carbon.

Value

A list of

LLWR.B	LLWR for Brazilian soils
LLWR.C	LLWR for Canadian soils

Author(s)

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References

Keller, T; Silva, A.P.; Tormena, C.A.; Giarola, N.B.F., Cavalieri, K.M.V., Stettler, M.; Arvidsson, J. 2015. SoilFlex-LLWR: linking a soil compaction model with the least limiting water range concept. *Soil Use and Management*, 31:321-329.

Silva, A.P.; Kay, B.D. 1997. Estimating the least limiting water range of soil from properties and management. *Soil Science Society of America Journal*, 61:877-883.

Silva, A.P., Kay, B.D.; Perfect, E. 1994. Characterization of the least limiting water range. *Soil Science Society of America Journal*, 61:877-883.

Silva, A.P., Tormena, C.A., Jonez, F.; Imhoff, S. 2008. Pedotransfer functions for the soil water retention and soil resistance to penetration curves. *Revista Brasileira de Ciencia do Solo*, 32:1-10.

Examples

```
# EXEMPLE 1 (for Brazilian Soils)
llwrPTF(air=0.1,critical.PR=2, h.FC=100, h.WP=15000,p.density=2.65,
        Bd=c(1.2,1.3,1.4,1.5,1.35),clay.content=c(30,30,35,38,40))

# EXEMPLE 2 (for Canadian Soils)
llwrPTF(air=0.1,critical.PR=2, h.FC=100, h.WP=15000,p.density=2.65,
        Bd=c(1.2,1.3,1.4),clay.content=c(30,30,30), org.carbon=c(1.3,1.5,2))

# EXEMPLE 3 (combining it with soil stress)
stress <- stressTraffic(inflation.pressure=200,
        recommended.pressure=200,
        tyre.diameter=1.8,
        tyre.width=0.4,
        wheel.load=4000,
        conc.factor=c(4,5,5,5,5,5),
                layers=c(0.05,0.1,0.3,0.5,0.7,1),
        plot.contact.area = FALSE)

stress.p <- stress$Stress$p
layers <- stress$Stress$Layers
n <- length(layers)
def <- soilDeformation(stress = stress.p,
                p.density = rep(2.67,n),
          iBD = rep(1.55,n),
                N = rep(1.9392,n),
                CI = rep(0.06037,n),
                k = rep(0.00608,n),
                k2 = rep(0.01916,n),
                m = rep(1.3,n),graph=TRUE,ylim=c(1.4,1.8))

# Grapth LLWR, considering Brazilian soils
plot(x = 1, y = 1,
     xlim=c(0,0.2),ylim=c(1,0),xaxt = "n",
     ylab = "Soil Depth",xlab ="", type="l", main="")
axis(3)
mtext("LLWR",side=3,line=2.5)

i.LLWR <- llwrPTF(air=0.1,critical.PR=2, h.FC=100,
                        h.WP=15000,p.density=2.65,
                        Bd=def$iBD,clay.content=rep(20,n))
f.LLWR <- llwrPTF(air=0.1,critical.PR=2, h.FC=100,
                        h.WP=15000,p.density=2.65,
                        Bd=def$fBD,clay.content=rep(20,n))

points(x=i.LLWR$LLWR.B, y=layers, type="l"); points(x=i.LLWR$LLWR.B, y=layers,pch=15)
points(x=f.LLWR$LLWR.B, y=layers, type="l", col=2); points(x=f.LLWR$LLWR.B, y=layers,pch=15, col=2)

# End (not run)
```

maxcurv *Maximum Curvature Point*

Description

Function to determine the maximum curvature point of an univariate nonlinear function of x.

Usage

```
 maxcurv(x.range, fun,
method = c("general", "pd", "LRP", "spline"),
x0ini = NULL,
graph = TRUE, ...)
```

Arguments

x.range	a numeric vector of length two, the range of x.
fun	a function of x; it must be a one-line-written function, with no curly braces '{}'.
method	a character indicating one of the following: "general" - for evaluating the general curvature function (k), "pd" - for evaluating perpendicular distances from a secant line, "LRP" - a NLS estimate of the maximum curvature point as the breaking point of Linear Response Plateau model, "spline" - a NLS estimate of the maximum curvature point as the breaking point of a piecewise linear spline. See details.
x0ini	an initial x-value for the maximum curvature point. Required only when "LRP" or "spline" are used.
graph	logical; if TRUE (default) a curve of `fun` is plotted.
...	further graphical arguments.

Details

The method "LRP" can be understood as an especial case of "spline". And both models are fitted via `nls`. The method "pd" is an adaptation of the method proposed by Lorentz et al. (2012). The "general" method should be preferred for finding *global* points. On the other hand, "pd", "LRP" and "spline" are suitable for finding *local* points of maximum curvature.

Value

A list of

fun	the function of x.
x0	the x critical value.
y0	the y critical value.
method	the method of determination (input).

Author(s)

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References

Lorentz, L.H.; Erichsen, R.; Lucio, A.D. (2012). Proposal method for plot size estimation in crops. *Revista Ceres*, 59:772–780.

See Also

function, curve

Examples

```
# Example 1: an exponential model
f <- function(x) exp(-x)
maxcurv(x.range = c(-2, 5), fun = f)

# Example 2: Gompertz Growth Model
Asym <- 8.5
b2 <- 2.3
b3 <- 0.6
g <- function(x) Asym * exp(-b2 * b3 ^ x)
maxcurv(x.range = c(-5, 20), fun = g)

# using "pd" method
maxcurv(x.range = c(-5, 20), fun = g, method = "pd")

# using "LRP" method
maxcurv(x.range = c(-5, 20), fun = g, method = "LRP", x0ini = 6.5)

# Example 3: Lessman & Atkins (1963) model for optimum plot size
a = 40.1
b = 0.72
cv <- function(x) a * x^-b
maxcurv(x.range = c(1, 50), fun = cv)

# using "spline" method
maxcurv(x.range = c(1, 50), fun = cv, method = "spline", x0ini = 6)

# End (not run)
```

`plotCIsigmaP` *Percentile Confidence Intervals for Simulated Preconsolidation Stress*

Description

Build and plot percentile confidence intervals for preconsolidation stress simulated from simSigmaP.

Usage

```
plotCIsigmaP(msim, conf.level = 0.95, shade.col = "orange",
ordered = TRUE, xlim = NULL, xlab = expression(sigma[P]),
las = 1, mar = c(4.5, 6.5, 2, 1), ...)
```

Arguments

msim	an object of class "simSigmaP".
conf.level	the confidence level for the intervals.
shade.col	a character or number indicating the color of the shaded area delimiting each CI. See colors.
ordered	logical; should the intervals be displayed according to the value of the simulated mean?
xlim	optional; a numeric vector of length two containing the limits of the x-axis.
xlab	optional; a character indicating the x-axis label.
las	optional; see par.
mar	optional; see par.
...	further graphical parameters; see par.

Value

A numeric matrix containing the simulated mean, coefficient of variation, lower and upper CI limits and the name of the method used to calculate the preconsolidation stress.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

See Also

simSigmaP, sigmaP

Examples

```
# input data: stress and void ratio
pres <- c(1, 12.5, 25, 50, 100, 200, 400, 800, 1600)
VR <- c(1.43, 1.41, 1.40, 1.39, 1.35, 1.31, 1.25, 1.18, 1.12)

# simulation (may take a few seconds)
simres <- simSigmaP(VR, pres, nsim = 50)
head(simres)

# percentile confidence intervals
ci <- plotCIsigmaP(simres, conf.level = 0.95,
shade.col = "blue", ordered = TRUE)
print(ci)

# End (Not run)
```

Rsq *Multiple R-squared*

Description

Function to calculate the *multiple R-squared* and the *adjusted R-squared* from a fitted model via lm or aov, i.e., linear models. For a model fitted via nls, nonlinear models, the *pseudo R-squared* is returned.

Usage

```
Rsq(model)
```

Arguments

model	a model fitted via lm, aov or nls.

Value

A list of

R.squared	the multiple R-squared (for linear models) or the Pseudo R-squared (for nonlinear models).
adj.R.squared	the adjusted R-squared.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

See Also

lm, summary.lm, aov, nls

Examples

```
# example 1 [linear model]
y <- rnorm(10)
x <- 1:10
fit <- lm(y ~ x)
summary(fit)
Rsq(fit)

# example 2 [nonlinear model for Load Bearing Capacity]
data(compaction)
attach(compaction)
out <- fitlbc(theta = Mois, sigmaP = PS)
summary(out)
Rsq(out)

# End (not run)
```

sigmaP *Preconsolidation Stress*

Description

A function to determine the preconsolidation stress (σ_P). It is a parameter obtained from the soil compression curve and has been used as an indicator of soil load-bearing capacity as well as to characterize the impacts suffered by the use of machines. The function `sigmaP()` contains implementations of the main methods for determining the pre-consolidation stress, such as the Casagrande method, the method of Pacheco Silva, the regression methods and the method of the virgin compression line intercept.

Usage

```
sigmaP(voidratio, stress, n4VCL = 3,
   method = c("casagrande", "VCLzero", "reg1", "reg2", "reg3", "reg4", "pacheco"),
    mcp = NULL, graph = TRUE, ...)
```

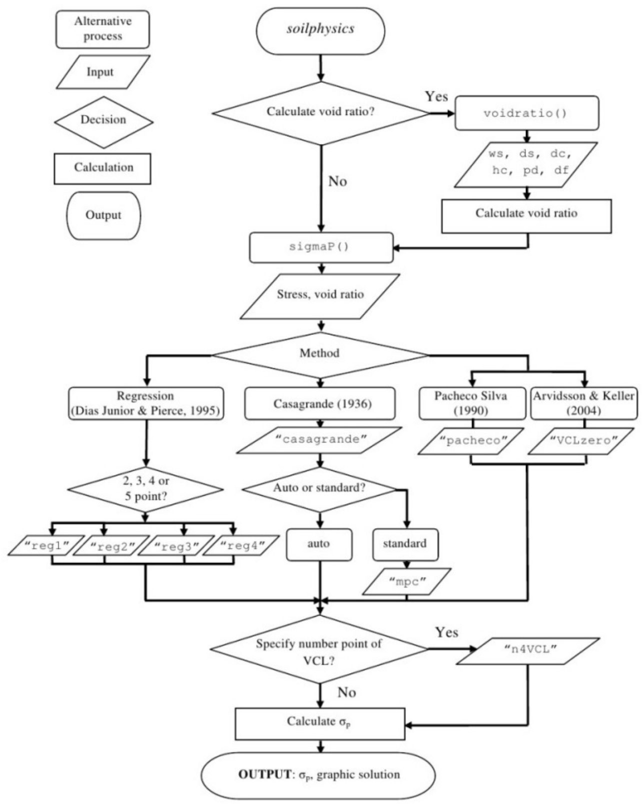
Arguments

`voidratio`	a numeric vector containing void ratio (or bulk density) values.
`stress`	a numeric vector containing the applied stress sequence.
`n4VCL`	the number of points for calculating the slope of the soil Virgin Compression Line (VCL), which is obtained by linear regression.
`method`	a character indicating which method is to be computed; one of the following: `casagrande` (default), `VCLzero`, `reg1`, `reg2`, `reg3`, `reg4` or `pacheco`; see Details.
`mcp`	the maximum curvature point in log10 scale of `stress`; required only if the method `casagrande` is used.
`graph`	logical; if TRUE (default) the compression curve is plotted.
`...`	further graphical arguments.

Details

`casagrande` is the method proposed by Casagrande (1936). The preconsolidation stress obtained via `VCLzero` corresponds to the intersection of the soil *Virgin Compression Line* (VCL) with the x-axis at zero applied stress, as described by Arvidsson & Keller (2004). `reg1`, `reg2`, `reg3` and `reg4` are regression methods that obtain the preconsolidation stress value as the intercept of the VCL and a regression line fitted with the first two, three, four and five points of the curve, respectively, as described by Dias Junior & Pierce (1995). `pacheco` is the method of Pacheco Silva (ABNT, 1990).

You may follow the flowchart below to understand the determination of the preconsolidation stress through `sigmaP()`.



ws - the weight of wet soil; ***ds*** - the weight of dry soil; ***dc*** - the diameter of the cylinder; ***hc*** - the heigth of the cylinder; ***pd*** - the particle density; ***df*** - a numeric vector containing soil deformation values; σ_p - preconsolidation pressure; ***VCL*** - Virgin Compression Line.

Value

A list of

- `sigmaP` the preconsolidation stress.
- `method` the method used as argument.
- `mcp` the maximum curvature point in log10 scale of `stress`; stored only if the method `casagrande` is used.
- `CI` the compression index.
- `SI` the swelling index.

Author(s)

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References

ABNT - Associacao Brasileira de Normas Tecnicas. (1990). *Ensaio de adensamento unidimensional*: NBR 12007. Rio de Janeiro. 13p.

Arvidsson, J.; Keller, T. (2004). Soil precompression stress I. A survey of Swedish arable soils. *Soil & Tillage Research*, 77:85-95.

Bowles, J. A. (1986). *Engineering Properties of Soils and their Measurements*, 3rd edition. McGraw-Hill Book Company, Inc. NY, 218pp.

Casagrande, A. (1936). *The determination of the pre-consolidation load and its practical significance*. In: Proceedings of the International Conference on Soil Mech. and Found. Eng. (ICSMFE), Cambridge, MA, 22-26 June 1936, vol. 3. Harvard University, Cambridge, MA, USA, pp. 60-64.

Dias Junior, M. S.; Pierce, F. J. (1995). A simple procedure for estimating preconsolidation pressure from soil compression curves. *Soil Technology*, 8:139-151.

See Also

voidratio, maxcurv, fitlbc

Examples

```
pres <- c(1, 12.5, 25, 50, 100, 200, 400, 800, 1600)
VR <- c(0.846, 0.829, 0.820, 0.802, 0.767, 0.717, 0.660, 0.595, 0.532)

plot(VR ~ log10(pres), type = "b") # find the 'mcp'
sigmaP(VR, pres, method = "casagrande", mcp = 1.6, n4VCL = 2)

# fitting the VCL
sigmaP(VR, pres, method = "casagrande", mcp = 1.6, n4VCL = 3)

# self-calculation of "mcp" argument for Casagrande method
sigmaP(VR, pres, method = "casagrande", n4VCL = 3)

# Pacheco method
sigmaP(VR, pres, method = "pacheco")

# Regression method
sigmaP(VR, pres, method = "reg3")

# End (not run)
```

simSigmaP — *Simulating Preconsolidation Stress*

Description

Simulating preconsolidation pressure, compression and swelling indices, based on a multivariate Gaussian distribution for the parameters of the compression curve.

Usage

```
simSigmaP(voidratio, stress,
what.out = c("sigmaP", "CI", "SI"),
method = c("casagrande", "VCLzero", "reg1", "reg2", "reg3", "reg4", "pacheco"),
n4VCL = 3, nsim = 100)
```

Arguments

`voidratio`	a numeric vector containing void ratio (or bulk density) values.
`stress`	a numeric vector containing the applied stress sequence.
`what.out`	a character indicating which `sigmaP()` output should be simulated. It must be on of "sigmaP" (default), "CI" of "SI".
`method`	a character vector indicating which methods should be used.
`n4VCL`	the number of points for calculating the slope of the soil Virgin Compression Line (VCL), which is obtained by linear regression. Default is 3.
`nsim`	the number of simulations. Default is 100. Warning: it may cause time demanding.

Value

A numeric matrix containing the simulated values for each method selected as input.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

See Also

`sigmaP`, `plotCIsigmaP`

Examples

```
# input data: stress and void ratio
pres <- c(1, 12.5, 25, 50, 100, 200, 400, 800, 1600)
VR <- c(1.43, 1.41, 1.40, 1.39, 1.35, 1.31, 1.25, 1.18, 1.12)

# simulation (may take a few seconds)
simres <- simSigmaP(VR, pres, nsim = 50)
```

```
head(simres)

# plot percentile confidence intervals
ci <- plotCIsigmaP(simres, conf.level = 0.95,
shade.col = "blue", ordered = TRUE)
print(ci)

# End (Not run)
```

Sindex *The S Index*

Description

Function to calculate the S index (Dexter, 2004) for evaluating the soil physical quality based on the *Water Retention Curve* (van Genuchten, 1980).

$$S = -n * (\theta_S - \theta_R) * (1 + 1/m)^{-(1+m)}$$

Usage

```
Sindex(theta_R, theta_S, alpha, n, m = 1 - 1/n, vcov = NULL,
nsim = 999, conf.level = 0.95, graph = TRUE, ...)
```

Arguments

theta_R	the residual water content.
theta_S	the water content at saturation.
alpha	a scale parameter of the van Genuchten's formula.
n	a shape parameter in van Genuchten's formula.
m	a shape parameter in van Genuchten's Formula. Default is $1 - 1/n$ (Mualem, 1976).
vcov	optional (default is `NULL`); a variance-covariance matrix of the estimates which is used to perform Monte Carlo simulations of the parameters `theta_R`, `theta_S`, `alpha` and `n` for building a simulated confidence interval of the S index (in modulus).
nsim	the number of Monte Carlo simulations; default is 999. It is used only if `vcov` is specified.
conf.level	the confidence level; default is 0.95. It is used only if `vcov` is specified.
graph	logical; if TRUE (defaul), the soil water retention curve is plotted.
...	further graphical arguments.

Value

A list of

h_i
: the modulus of the water potential at the inflection point.

theta_i
: the water content at the inflection point.

S.index
: the modulus of the S index.

PhysicalQuality
: A character indicating the soil physical quality, as proposed by Dexter (2004).

simCI
: the simulated confidence interval. It is stored only if vcov is specified.

conf.level
: the confidence level for the simulated confidence interval. It is stored only if vcov is specified.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dexter, A. R. (2004). Soil physical quality Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. *Geoderma*, 120:201-214.

Genuchten, M. T. van. (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal*, 44:892-898.

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media, *Water Resource Research*, 12:513-522.

See Also

soilwater, fitsoilwater

Examples

```
# Dexter (2004, Table 1)
Sindex(0, 0.395, 0.0217, 1.103, xlim = c(0, 1000))
Sindex(0, 0.335, 0.0616, 1.139, xlim = c(0, 1000))
# ...
Sindex(0, 0.226, 0.0671, 1.581, xlim = c(0, 1000))

# End (not run)
```

skp1994 *LLWR Data Set*

Description

Data set presented by Leao et al. (2005), for determining the Least Limiting Water Range.

Usage

```
data(skp1994)
```

Format

A data frame with 64 observations on the following 4 variables:

`BD` a numeric vector containing soil bulk density values, in Mg/m3.

`W` a numeric vector containing volumetric water content values, in m3/m3.

`PR` a numeric vector containing penetration resistance values, in MPa.

`h` a numeric vector containing matric head values, in cm.

Source

Leao et al. (2005). An Algorithm for Calculating the Least Limiting Water Range of Soils. *Agronomy Journal*, 97:1210-1215.

Examples

```
data(skp1994)
summary(skp1994)
```

soilDeformation *Soil deformation by O'Sullivan and Robertson (1996)*

Description

It calculates bulk density variation as a function of the applied mean normal stress using critical state theory, by O'Sullivan and Robertson (1996).

Usage

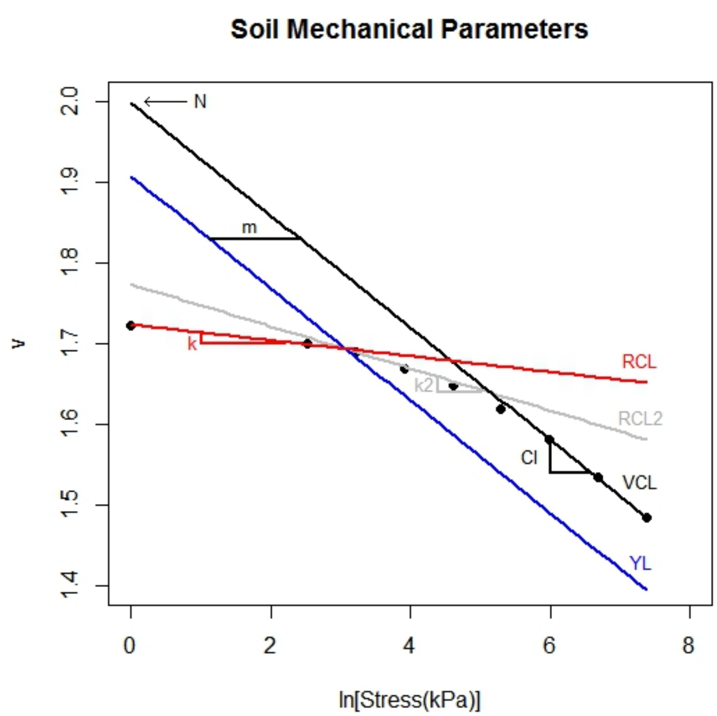
```
soilDeformation(stress, p.density, iBD, N, CI, k, k2, m, graph = FALSE, ...)
```

Arguments

`stress`	a numeric vector containing the values of mean normal stress, kPa; Note that stress can also be a vector of length 1.
`p.density`	a numeric vector containing the values of particle density to each stress, Mgm^{-3}.
`iBD`	a numeric vector containing the values of initial bulk density to each stress, Mgm^{-3}.
`N`	the specific volume at p = 1 kPa, to each stress
`CI`	the compression index, to each stress; check details
`k`	the recompression index, to each stress; check details
`k2`	the slope of the steeper recompression line to each stress (similar to the k' in O'Sullivan and Robertson (1996) model); check details
`m`	the value that separates yield line and VCL to each stress; check details
`graph`	logical; shall soilDeformation plot the graph model (only the first parameters set is ploted)?
`...`	further graphical arguments. See par.

Details

The specific volume (v) is given as $v = PD/BD$, where PD is particle density and BD is the bulk density. Please, check each parameter from O'Sullivan and Robertson (1996) model in the figure below.



Value

A list of

iBD	initial bulk density, Mgm^{-3}
fBD	final bulk density, Mgm^{-3}
vi	initial specific volume
vf	final specific volume
I%	variation of soil bulk density (%) after the applied stress

Author(s)

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Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

Alvaro Pires da Silva <apisilva@usp.br>

References

O'Sullivan, M.F.; Robertson, E.A.G. 1996. Critical state parameters from intact samples of two agricultural soils. *Soil and Tillage Research*, 39:161-173.

Keller, T.; Defossez, P.; Weisskopf, P.; Arvidsson, J.; Richard, G. 2007. SoilFlex: a model for prediction of soil stresses and soil compaction due to agricultural field traffic including a synthesis of analytical approaches. *Soil and Tillage Research*, 93:391-411.

Examples

```
# EXAMPLE 1
soilDeformation(stress = 300,
                p.density = 2.67,
        iBD = 1.55,
                N = 1.9392,
                CI = 0.06037,
                k = 0.00608,
                k2 = 0.01916,
                m = 1.3,graph=TRUE,ylim=c(1.4,1.8))

# EXEMPLE 2 (combining it with soil stress)
stress <- stressTraffic(inflation.pressure=200,
        recommended.pressure=200,
        tyre.diameter=1.8,
        tyre.width=0.4,
        wheel.load=4000,
        conc.factor=c(4,5,5,5,5,5),
                layers=c(0.05,0.1,0.3,0.5,0.7,1),
        plot.contact.area = FALSE)

stress.p <- stress$Stress$p
layers <- stress$Stress$Layers
n <- length(layers)
```

```
def <- soilDeformation(stress = stress.p,
                p.density = rep(2.67, n),
          iBD = rep(1.55,n),
                N = rep(1.9392,n),
                CI = rep(0.06037,n),
                k = rep(0.00608,n),
                k2 = rep(0.01916,n),
                m = rep(1.3,n),graph=TRUE,ylim=c(1.4,1.8))

# Graph
plot(x = 1, y = 1,
     xlim=c(1.4,1.7),ylim=c(1,0),xaxt = "n",
     ylab = "Soil Depth",xlab ="", type="l", main="")
axis(3)
mtext("Bulk Density",side=3,line=2.5)

initial.BD <- def$iBD
final.BD <- def$fBD
points(x=initial.BD, y=layers, type="l")
points(x=initial.BD, y=layers,pch=15)
points(x=final.BD, y=layers, type="l", col=2)
points(x=final.BD, y=layers,pch=15, col=2)

# End (not run)
```

`soilStrength` *Estimation of the Load Bearing Capacity by precompression stress*

Description

Calculates the soil strength using precompression stress for different clay contents and matric suction.

Usage

```
soilStrength(clay.content, matric.suction = NULL, water.content = NULL)
```

Arguments

`clay.content`	a numeric vector containing the values of clay for each soil layer, %. Note that it can also be a unique value.
`matric.suction`	a numeric vector containing the values of matric suction for each clay content, hPa.
`water.content`	a numeric vector containing the values of water content for each clay content, $m^3 m^{-3}$. Note that water.content must be passed if `matric.suction` is not. See details.

Details

Intervals of soil water content/matric suction to be used as input for estimating soil strength according to Severiano et al. (2013).

Clay content (%)	Matric head (kPa)	Water content (m^3 m^{-3})
< 20	1-10,000	0.05-0.42
21-31	1-10,000	0.09-0.45
32-37	1-10,000	0.11-0.46
38-52	1-10,000	0.13-0.50
> 52	1-10,000	0.14-0.51

Value

A two-columns data frame:

`Pc`	the precompression stress (Severiano et al. 2013)
`LL.Pc`	the lower limit of precompression stress in acoording to the Terranimo model criteria (see Stettler et al. 2014). Note: LL.Pc = Pc*0.5
`UL.Pc`	the upper limit of precompression stress in acoording to the Terranimo model criteria (see Stettler et al. 2014). Note: UL.Pc = Pc*1.1

Author(s)

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References

Severiano, E.C; Oliveira, G.C.; Dias Junior, M.S.; Curi, N.C.; Costa, K. A.P.; Carducci, C.E. 2013. Preconsolidation pressure, soil water retention characteristics, and texture of Latosols in the Brazilian Cerrado. *Soil Research*, 51:193-202.

Stettler, M., Keller, T., Weisskopf, P., Lamande, M., Lassen, P., Schjonning, P., 2014. Terranimo - a web-based tool for evaluating soil compaction. *Landtechnik*, 69:132-137.

See Also

stressTraffic

Examples

```
# EXEMPLE 1 (using water content)
soilStrength(clay.content=c(25,28,30,30,30),
             water.content = c(0.26,0.27,0.29,0.32,0.32))


# EXEMPLE 2 (using matric suction)
```

```
soilStrength(clay.content=c(25,28,30,30,30),
             matric.suction = c(100,330,1000,3000,5000))


# EXAMPLE 3 (combining it with soil stress)
stress <- stressTraffic(inflation.pressure=200,
        recommended.pressure=200,
        tyre.diameter=1.8,
        tyre.width=0.4,
        wheel.load=4000,
        conc.factor=c(4,5,5,5,5,5),
              layers=c(0.05,0.1,0.3,0.5,0.7,1),
        plot.contact.area = FALSE)

strength <- soilStrength(clay.content=c(25,28,30,30,30,30),
              matric.suction = c(30,100,100,100,200,200))


# Graph
plot(x = 1, y = 1,
     xlim=c(0,300),ylim=c(1,0),xaxt = "n",
     ylab = "Soil Depth",xlab ="", type="l", main="")
axis(3)
mtext("Vertical Stress",side=3,line=2.5)

stressz <- stress$Stress$Z
layers <- stress$Stress$Layers
points(x=stressz, y=layers, type="l")

# Green zone
x0 <- strength$LL.Pc
x1 <- rep(0,length(layers))
y0 <- layers
y1 <- rev(layers)
polygon(x=c(x0,x1), y = c(y0,y1),density = NA,
       col=rgb(red=0, green=1, blue=0, alpha=0.3))

# Yellow zone
x0 <- strength$UL.Pc
x1 <- rev(strength$LL.Pc)
y0 <- layers
y1 <- rev(layers)
polygon(x=c(x0,x1), y = c(y0,y1),density = NA,
       col=rgb(red=1, green=1, blue=0, alpha=0.3))

# Red zone
x0 <- rep(300,length(layers))
x1 <- rev(strength$UL.Pc)
y0 <- layers
y1 <- rev(layers)
polygon(x=c(x0,x1), y = c(y0,y1),density = NA,
       col=rgb(red=1, green=0, blue=0, alpha=0.3))
```

```
# End (not run)
```

`soilwater` *Soil Water Retention, based on the van Genuchten's (1980) formula*

Description

Function to calculate the soil water content based on the van Genuchten's (1980) formula:

$$\theta = \theta_R + (\theta_S - \theta_R)(1 + (\alpha x)^n)^{-m}$$

Usage

```
soilwater(x, theta_R, theta_S, alpha, n, m = 1 - 1/n,
    saturation.index = FALSE)
```

Arguments

`x`	the matric potential.
`theta_R`	the residual water content.
`theta_S`	the water content at saturation.
`alpha`	a scale parameter of the van Genuchten's formula.
`n`	a shape parameter in van Genuchten's formula.
`m`	a shape parameter in van Genuchten's Formula. Default is $1 - 1/n$ (Mualem, 1976).
`saturation.index`	logical; if FALSE (default) the outcome is the soil water content, otherwise the saturation index is returned.

Value

The the soil water content or the saturation index (a value between 0 and 1).

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com> (code adapted from the function swc(), package *soilwater* (Cordano *et al*., 2012).)

References

Genuchten, M. T. van. (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal*, 44:892-898.

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water Resources Research*, 12:513-522.

See Also

fitsoilwater

Examples

```
# example 1
soilwater(x = 0.1, theta_R = 0.06, theta_S = 0.25, alpha = 21, n = 2.08)
curve(soilwater(x, theta_R = 0.06, theta_S = 0.25, alpha = 21, n = 2.08))

# example 2 (punctual predictions)
p <- seq(0, 1, length.out = 10)
m <- soilwater(x = p, theta_R = 0.06, theta_S = 0.25,
alpha = 21, n = 2.08)
points(m ~ p, type = "b", col = "red")

# End (not run)
```

---

soilwater2 — *Soil Water Retention, based on the Groenevelt & Grant (2004) formula*

Description

Function to calculate the soil water content based on the Groenevelt & Grant (2004) model. It is based on thermodynamic principles. Therefore, it is appropriate for the case in which thermodynamic equilibrium has been attained by diffusion of water. In this case, the water retention curve is given by:

$$\theta = k_1 \exp(-k_0/x_0^n) - k_1 \exp(-k_0/x^n)$$

where $x = logh$ (pore water suction), and h is in units of hPa

Usage

```
soilwater2(x, x0 = 6.653, k0, k1, n)
```

Arguments

x	a numeric vector containing pF values.
x0	the value of pF (pore water suction) at which the soil water content becomes zero. The default is 6.653.
k0	a parameter value.
k1	a parameter value.
n	a parameter value.

Value

The the soil water content.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Groenevelt & Grant (2004). A newmodel for the soil-water retention curve that solves the problem of residualwater contents. *European Journal of Soil Science*, 55:479-485.

See Also

fitsoilwater2, soilwater

Examples

```
pF <- 0:7
soilwater2(pF, k0 = 1.867, k1 = 0.426, n = 2.358)

# End (not run)
```

---

soilwater3 *Soil Water Retention, based on the Dexter's (2008) formula*

Description

Function to calculate the soil water content based on the Dexter's (2008) formula. It is based on the segregation of pore space in two categories what are called bi-modal pore size distributions. In this model, the pore space is divided into two parts: the textural porosity which occurs between the primary mineral particles, and the structural porosity which occurs between micro aggregates and/or any other compound particles. This is called the double-exponential (DE) water retention equation, given by:

$$\theta = \theta_R + a_1 \exp(-x/p_1) + a_2 \exp(-x/p_2)$$

where θ is the gravimetric water content.

Usage

```
soilwater3(x, theta_R, a1, p1, a2, p2)
```

Arguments

`x`	a numeric vector containing the values of applied air pressure.
`theta_R`	a parameter that represents the residual water content.
`a1`	a parameter that represents the drainable part of the textural pore space in units of gravimetric water content at saturation.
`p1`	a parameter that represents the applied air pressures characteristic for displacement of water from the textural pore space.
`a2`	a parameter that represents the total structural pore space in units of gravimetric water content at saturation.
`p2`	a parameter that represents the applied air pressure that is characteristic for displacing water from the structural pores.

Value

The the soil water content.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dexter et al. (2008). A user-friendly water retention function that takes account of the textural and structural pore spaces in soil. *Geoderma*, 143:243-253.

See Also

`fitsoilwater3`, `soilwater`, `soilwater2`

Examples

```
soilwater3(x = 0, theta_R = 0.058, a1 = 0.233, p1 = 3.274, a2 = 0.070, p2 = 1.78)
soilwater3(x = 3, theta_R = 0.058, a1 = 0.233, p1 = 3.274, a2 = 0.070, p2 = 1.78)
soilwater3(x = 4, theta_R = 0.058, a1 = 0.233, p1 = 3.274, a2 = 0.070, p2 = 1.78)

# End (not run)
```

`soilwater4` *Soil Water Retention, based on Power Models*

Description

Function to calculate the soil water content based on the following formulas:

$$\theta = \exp(a + b * Bd)\psi^c$$

(Silva et al., 1994)

$$\theta = a\psi^c$$

(Ross et al., 1991)

where θ is the soil water content.

Usage

```
soilwater4(psi, Bd, a, b, c, model = c("Silva", "Ross"))
```

Arguments

`psi`	a numeric vector containing values of water potential (Psi).
`Bd`	a numeric vector containing values of dry bulk density.
`a`	a model-fitting parameter. See details.
`b`	a model-fitting parameter. See details.
`c`	a model-fitting parameter. See details.
`model`	a character; the model to be used for calculating the soil water content. It must be one of the two: `"Silva"` (default) or `"Ross"`.

Details

The parameters "a" and "c" have the same meaning in both models, but be aware that the parameter "a" of the model employed by Silva et al. (1994) is parameter "a" of the Ross et al. (1991) in a log10 scale.

Value

The the soil water content.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Ross et al. (1991). Equation for extending water-retention curves to dryness. *Soil Science Society of America Journal*, 55:923-927.

Silva et al. (1994). Characterization of the least limiting water range of soils. *Soil Science Society of America Journal*, 58:1775-1781.

See Also

fitsoilwater4, soilwater, soilwater2, soilwater3

Examples

```
# End (not run)
```

---

soilwater5 *Soil Water Retention, based on the modified van Genuchten's formula*

Description

Function to calculate the soil water content based on the modified van Genuchten's formula, as suggested by Pierson and Mulla (1989):

$$\theta = \theta_R + (\theta_S - \theta_R)(1 + (\alpha x)^n)^{-m} + b_0 + b_1 x + b_2 * x^2$$

Usage

```
soilwater5(x, theta_R, theta_S, alpha, n, m = 1 - 1/n, b0, b1, b2)
```

Arguments

x	the matric potential.
theta_R	the residual water content.
theta_S	the water content at saturation.
alpha	a scale parameter of the van Genuchten's formula.
n	a shape parameter in van Genuchten's formula.
m	a shape parameter in van Genuchten's Formula. Default is $1 - 1/n$ (Mualem, 1976).
b0	a parameter added to the van Ganuchten's formula.
b1	a parameter added to the van Ganuchten's formula.
b2	a parameter (of quadratic term) added to the van Ganuchten's formula.

Value

The the soil water content or the saturation index (a value between 0 and 1).

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Pierson, F.B.; Mulla, D.J. (1989) An Improved Method for Measuring Aggregate Stability of a Weakly Aggregated Loessial Soil. *Soil Sci. Soc. Am. J.*, 53:1825–1831.

See Also

fitsoilwater5

Examples

```
soilwater5(x = 20, theta_R = 0.2735, theta_S = 0.478, alpha = 0.1029,
n = 9.45, b0 = 0.2278, b1 = -0.0165, b2 = 0.000248)
curve(soilwater5(x, theta_R = 0.2735, theta_S = 0.478, alpha = 0.1029,
n = 9.45, b0 = 0.2278, b1 = -0.0165, b2 = 0.000248),
from = 0, to = 40,
ylab = "Water content",
xlab = "Matric potential")

# End (Not run)
```

SSlbc — *Self-Starting Nls Load Bearing Capacity Model*

Description

A selfStart model that evaluates the Load Bearing Capacity (Dias Jr., 1994) function and its gradient. It has an initial attribute that creates initial estimates of the parameters b0 and b1.

Usage

```
SSlbc(theta, b0, b1)
```

Arguments

theta	a numeric vector of soil moisture values at which to evaluate the model.
b0	a numeric parameter.
b1	a numeric parameter.

Value

a numeric vector with the same length of `theta`. It is the value of the expression $10^{(b0+b1*\theta)}$. Also, the gradient matrix with respect to the parameters is attached as an attribute named *gradient*.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

References

Dias Junior, M. S. (1994). *Compression of three soils under longterm tillage and wheel traffic*. 1994. 114p. Ph.D. Thesis - Michigan State University, East Lansing.

See Also

getInitiallbc, fitlbc, selfStart, nls, sigmaP

Examples

```
data(compaction)
attach(compaction)
ss <- SSlbc(Mois, 2.79, -2.33)
ss[1:50] # prediction
PS # original data of preconsolidation stress
ss # prediction and gradient

# End (not run)
```

---

stressTraffic *Predicting Soil Stress Due to Agricultural Trafficability*

Description

Contact area, stress distribuition and stress propagation based on the SoilFlex model (Keller 2005; Keller et al. 2007) are calculated.

Usage

```
stressTraffic(inflation.pressure, recommended.pressure, tyre.diameter,
    tyre.width, wheel.load, conc.factor, layers, plot.contact.area = FALSE, ...)
```

Arguments

`inflation.pressure`	tyre inflation pressure, kPa
`recommended.pressure`	recommended tyre inflation pressure at given load, kPa
`tyre.diameter`	overall diameter of the unloaded tyre, m
`tyre.width`	tyre width, m
`wheel.load`	wheel load, kg
`conc.factor`	concentration factor; a numeric vector ranging from 3 (wet soil) to 6 (dry soil), depending on water content.
`layers`	a numeric vector containing values of depth (in meters) for the soil layers. Note that layers can also be a unique value
`plot.contact.area`	logical; shall `soilTraffic` plot the distribution of stress over the contact area?
`...`	further graphical arguments. See par.

Value

A list of

Area	Contact area parameters.
Loads	Estimated wheel loads.
Stress	Stress propagation into soil.
stress.matrix	The matrix of applied stress at a specific depth and radial distance from the tyre centre.
fZStress	The function of stress propagation in z direction (vertical stress).
fmeanStress	The function of normal mean stress propagation.
fStress	The function of stress propagation.
fXStress	The function of stress propagation in x (footprint length or driving) direction.
fYStress	The function of stress propagation in y (tire width) direction.

Author(s)

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Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

Alvaro Pires da Silva <apisilva@usp.br>

References

Keller, T. 2005. A model to predict the contact area and the distribution of vertical stress below agricultural tyres from readily-available tyre parameters. *Biosyst. Eng.* 92, 85-96.

Keller, T.; Defossez, P.; Weisskopf, P.; Arvidsson, J.; Richard, G. 2007. SoilFlex: a model for prediction of soil stresses and soil compaction due to agricultural field traffic including a synthesis of analytical approaches. *Soil and Tillage Research* 93, 391-411.

Examples

```
stress <- stressTraffic(inflation.pressure=200,
   recommended.pressure=200,
   tyre.diameter=1.8,
   tyre.width=0.4,
   wheel.load=4000,
   conc.factor=c(4,5,5,5,5,5),
           layers=c(0.05,0.1,0.3,0.5,0.7,1),
   plot.contact.area = TRUE)

stress

# Building a fancier plot for the contact area
# library(fields)
# image.plot(x = as.numeric(rownames(stress$stress.matrix)),
#        y = as.numeric(colnames(stress$stress.matrix)),
#        z = stress$stress.matrix,
#        xlab="Tyre footprint length (m)", ylab="Tyre width (m)")
```

```
# End (not run)

# Stress Propagation
# Vertical Stress
stress.v <- stress$Stress$Zstress
layers <- stress$Stress$Layers
plot(x = 1, y = 1, xlim=c(0,300),ylim=c(1,0),xaxt = "n",
     ylab = "Soil Depth",xlab ="", type="l", main="")
axis(3)
mtext("Stress (kPa)",side=3,line=2.5)
lines(x=stress.v, y=layers)

# Mean normal stress
stress.p <- stress$Stress$p
lines(x=stress.p, y=layers, lty=2)
legend("bottomright", c("Vertical stress", "Normal mean stress"), lty = 1:2)

# End (not run)
```

---

voidratio *Void Ratio*

Description

A function to calculate the soil void ratio.

Usage

```
voidratio(wetsoil, drysoil, diam.cylinder, height.cylinder,
    dens.particle, deformation)
```

Arguments

- `wetsoil` the weight of wet soil.
- `drysoil` the weight of dry soil.
- `diam.cylinder` the diameter of the cylinder.
- `height.cylinder` the heigth of the cylinder.
- `dens.particle` the particle density.
- `deformation` a numeric vector containing soil deformation values.

Value

A numeric vector with same length of `deformation` containig void ratio values.

Author(s)

Anderson Rodrigo da Silva <anderson.agro@hotmail.com>

See Also

sigmaP

Examples

```
def <- c(0, 0.0230, 0.0352, 0.0605, 0.1070, 0.1750, 0.2525, 0.3395, 0.4250)
pres <- c(1, 12.5, 25, 50, 100, 200, 400, 800, 1600)
VR <- voidratio(wetsoil = 170.62, drysoil = 134.08, diam.cylinder = 6.95,
               height.cylinder = 2.5, dens.particle = 2.61, def)
VR

plot(VR ~ pres, type = "b",
ylab = "Void ratio",
xlab = "Applied stress (kPa)",
main = "Compression curve",
log = "x")

# End (not run)
```

Index