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### Soil CO2 efflux from two mountain forests in the Eastern Himalayas Bhutan:
### components and controls

### by Wangdi et al.

### R code for modelling heterotrophic respiration by means of laboratory
### incubation data, soil carbon (C) stocks and continuous soil climate data

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#### Set working directory

setwd("D:/Buthan/FinalVersion")

#### Read continous soil climate data

## Broadleaved forest

BF = read.csv("SoilClimate_BroadleavedForest.csv", sep = ";")

## Mixed forest

MF = read.csv("SoilClimate_MixedForest.csv", sep = ";")

#### Variable description:

# site: BF = broadleaved forest; MF = mixed forest
# VWC_5cm: volumetric soil water content (vol.%) measured in 5 cm depth
# VWC_20cm: volumetric soil water content (vol.%) measured in 20 cm depth
# T_5cm: soil temperature (°C) measured in 5 cm depth
# T_20cm: soil temperature (°C) measured in 20 cm depth
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# All values are daily mean values

#### Set parameters

## Temperature response function (Equation 1)

## Broadleaved forest

# Forest floor litter

BF_Lit_T_b0 = 0.265

BF_Lit_T_b1 = 0.0793

# Mineral soil

BF_Min_T_b0 = 0.0961

BF_Min_T_b1 = 0.0828

## Mixed forest

# Forest floor litter

MF_Lit_T_b0 = 0.548

MF_Lit_T_b1 = 0.0645

# Mineral soil

MF_Min_T_b0 = 0.0701

MF_Min_T_b1 = 0.0808

### Moisture response function (Equation 3)

## Broadleaved forest

# Mineral soil only

BF_M_b0 =  0.0080456

BF_M_b1 =  0.01194

BF_M_b2 = -0.00012588

## Mixed forest

# Mineral soil only

MF_M_b0 = -0.086751

MF_M_b1 =  0.017487

MF_M_b2 = -0.00020757

### Soil moisture (vol.%)of samples during first incubations (see Table 2)

## Broadleaved forest

# Forest floor litter

BF_M_Inc_Lit = 46

# Mineral soil

BF_M_Inc_Min = 35

## Mixed forest

# Forest floor litter

MF_M_Inc_Lit = 46

# Mineral soil

MF_M_Inc_Min = 33

### Soil carbon stocks (kg/m²) (see Table 1)

## Broadleaved forest

# Annual litter input (proxy for litter C stock)

BF_C_Lit = 0.34

# Mineral soil C stocks in 0-10 cm depth (data from 4 soil pits)

BF_C_Min_0_10 = c(6.04, 7.00, 5.46, 3.71)

# Mineral soil C stocks in 10-20 cm depth (data from 4 soil pits)

BF_C_Min_10_30 = c(3.69, 4.01, 3.04, 3.10)

## Mixed forest

# Annual litter input (proxy for litter C stock)

MF_C_Lit =  0.35

# Mineral soil C stocks in 0-10 cm depth (data from 4 soil pits)

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MF_C_Min_0_10 = c(5.34, 6.71, 4.83, 7.28)

# Mineral soil C stocks in 10-20 cm depth (data from 4 soil pits)

MF_C_Min_10_30 = c(8.53, 7.46, 6.16, 9.91)


#### Modelling heterotrophic respiration (Rh) for each layer


## Broadleaved forest


BF_matrix = matrix(nrow=nrow(BF), ncol=4)  # empty matrix

BF_matrix_mineral = matrix(nrow=nrow(BF), ncol=4)

BF_matrix_mineral_10_30 = matrix(nrow=nrow(BF), ncol=4)

for (i in 1:nrow(BF)) {

   for (j in 1:4) {

      BF_matrix[i,j] =

         # Forest floor litter


         (((BF_Lit_T_b0 * exp(BF_Lit_T_b1 * BF$T_5cm[i])) * # Modell Rh with Temp

         BF_C_Lit * # Multiply by C stocks

         ((BF_M_b0 + BF_M_b1 * BF$VWC_5cm[i] + BF_M_b2 * BF$VWC_5cm[i] ^ 2) / # Correct for
field moisture
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(BF_M_b0 + BF_M_b1 * BF_M_Inc_Lit + BF_M_b2 * BF_M_Inc_Lit ^ 2)))

+

# Mineral soil 0-10 cm depth


((BF_Min_T_b0 * exp(BF_Min_T_b1 * BF$T_5cm[i])) *

BF_C_Min_0_10[j] *

((BF_M_b0 + BF_M_b1 * BF$VWC_5cm[i] + BF_M_b2 * BF$VWC_5cm[i] ^ 2) /

(BF_M_b0 + BF_M_b1 * BF_M_Inc_Min + BF_M_b2 * BF_M_Inc_Min ^ 2)))

+

# Mineral soil 10-30 cm depth


((BF_Min_T_b0 * exp(BF_Min_T_b1 * BF$T_20cm[i])) *

BF_C_Min_10_30[j] *

((BF_M_b0 + BF_M_b1 * BF$VWC_20cm[i] + BF_M_b2 * BF$VWC_20cm[i]^2) /

(BF_M_b0 + BF_M_b1 * BF_M_Inc_Min + BF_M_b2 * BF_M_Inc_Min ^ 2))))


BF_matrix_mineral[i,j] =
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 # Mineral soil 0-10 cm depth

 (((BF_Min_T_b0 * exp(BF_Min_T_b1 * BF$T_5cm[i])) *

 BF_C_Min_0_10[j] *

 ((BF_M_b0 + BF_M_b1 * BF$VWC_5cm[i] + BF_M_b2 * BF$VWC_5cm[i] ^ 2) /

 (BF_M_b0 + BF_M_b1 * BF_M_Inc_Min + BF_M_b2 * BF_M_Inc_Min ^ 2)))

 +

 # Mineral soil 10-30 cm depth

 ((BF_Min_T_b0 * exp(BF_Min_T_b1 * BF$T_20cm[i])) *

 BF_C_Min_10_30[j] *

 ((BF_M_b0 + BF_M_b1 * BF$VWC_20cm[i] + BF_M_b2 * BF$VWC_20cm[i]^2) /

 (BF_M_b0 + BF_M_b1 * BF_M_Inc_Min + BF_M_b2 * BF_M_Inc_Min ^ 2))))

BF_matrix_mineral_10_30[i,j] =

 # Mineral soil 10-30 cm depth

 ((BF_Min_T_b0 * exp(BF_Min_T_b1 * BF$T_20cm[i])) *
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        BF_C_Min_10_30[j] *

        ((BF_M_b0 + BF_M_b1 * BF$VWC_20cm[i] + BF_M_b2 * BF$VWC_20cm[i]^2) /

        (BF_M_b0 + BF_M_b1 * BF_M_Inc_Min + BF_M_b2 * BF_M_Inc_Min ^ 2)))


      }
        }


# Calculate mean values in µmol CO2 kgC^-1 sec^-1

BF$Rh = apply(BF_matrix, 1, FUN = mean)

BF$Rh_Min = apply(BF_matrix_mineral, 1, FUN = mean)

BF$Rh_Min_10_30 = apply(BF_matrix_mineral_10_30, 1, FUN = mean)




## Mixed forest

MF_matrix = matrix(nrow=nrow(MF), ncol=4)

MF_matrix_mineral = matrix(nrow=nrow(MF), ncol=4)

MF_matrix_mineral_10_30 = matrix(nrow=nrow(MF), ncol=4)

for (i in 1:nrow(MF)) {

   for (j in 1:4) {
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MF_matrix[i,j] =

    # Forest floor litter

    (((MF_Lit_T_b0 * exp(MF_Lit_T_b1 * MF$T_5cm[i])) * # Modell Rh with Temp

    MF_C_Lit * # Multiply by C stocks

    ((MF_M_b0 + MF_M_b1 * MF$VWC_5cm[i] + MF_M_b2 * MF$VWC_5cm[i] ^ 2) / # Correct for field moisture

    (MF_M_b0 + MF_M_b1 * MF_M_Inc_Lit + MF_M_b2 * MF_M_Inc_Lit ^ 2)))

    +

    # Mineral soil 0-10 cm depth

    ((MF_Min_T_b0 * exp(MF_Min_T_b1 * MF$T_5cm[i])) *

    MF_C_Min_0_10[j] *

    ((MF_M_b0 + MF_M_b1 * MF$VWC_5cm[i] + MF_M_b2 * MF$VWC_5cm[i] ^ 2) /

    (MF_M_b0 + MF_M_b1 * MF_M_Inc_Min + MF_M_b2 * MF_M_Inc_Min ^ 2)))

    +

    # Mineral soil 10-30 cm depth

    ((MF_Min_T_b0 * exp(MF_Min_T_b1 * MF$T_20cm[i])) *
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  MF_C_Min_10_30[j] *

  ((MF_M_b0 + MF_M_b1 * MF$VWC_20cm[i] + MF_M_b2 * MF$VWC_20cm[i]^2) /

  (MF_M_b0 + MF_M_b1 * MF_M_Inc_Min + MF_M_b2 * MF_M_Inc_Min ^ 2))))


MF_matrix_mineral[i,j] =


  # Mineral soil 0-10 cm depth


  (((MF_Min_T_b0 * exp(MF_Min_T_b1 * MF$T_5cm[i])) *

  MF_C_Min_0_10[j] *

  ((MF_M_b0 + MF_M_b1 * MF$VWC_5cm[i] + MF_M_b2 * MF$VWC_5cm[i] ^ 2) /

  (MF_M_b0 + MF_M_b1 * MF_M_Inc_Min + MF_M_b2 * MF_M_Inc_Min ^ 2)))

  +

  # Mineral soil 10-30 cm depth


  ((MF_Min_T_b0 * exp(MF_Min_T_b1 * MF$T_20cm[i])) *

  MF_C_Min_10_30[j] *

  ((MF_M_b0 + MF_M_b1 * MF$VWC_20cm[i] + MF_M_b2 * MF$VWC_20cm[i]^2) /
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(MF_M_b0 + MF_M_b1 * MF_M_Inc_Min + MF_M_b2 * MF_M_Inc_Min ^ 2))))

MF_matrix_mineral_10_30[i,j] =

# Mineral soil 10-30 cm depth

((MF_Min_T_b0 * exp(MF_Min_T_b1 * MF$T_20cm[i])) *

MF_C_Min_10_30[j] *

((MF_M_b0 + MF_M_b1 * MF$VWC_20cm[i] + MF_M_b2 * MF$VWC_20cm[i]^2) /

(MF_M_b0 + MF_M_b1 * MF_M_Inc_Min + MF_M_b2 * MF_M_Inc_Min ^ 2)))

    }
      }

# Calculate mean values in µmol CO2 kgC^-1 sec^-1

MF$Rh = apply(MF_matrix, 1, FUN = mean)

MF$RhSE = apply(MF_matrix, 1, FUN = std.error)

MF$Rh_Min = apply(MF_matrix_mineral, 1, FUN = mean)

MF$Rh_Min_10_30 = apply(MF_matrix_mineral_10_30, 1, FUN = mean)
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