CO2 emissions in layered cranberry soils under simulated warming

Wilfried Dossou-Yovo, Ph.D.

13/02/2022

Contents


```
print(Sys.Date())
```

```
## [1] "2023-01-08"
```

```
a <- list(10, TRUE, 5.6)

ls(pat = "^V")
```

```
## character(0)
```

1 Objective

This notebook generate the result of CO2 data analysis. Data set contains a collection of soil characteristics, measured co2 emission collected from incubation study. Soil samples was collected from two cranberry field stand of eastern Canada. Incubation study was carried out at Agriculture and Agri-food Canada(Sainte-foy, Quebec,qc) from February to Mai 2019. The aim of this study was to measure CO2 emission rates in cranberry soils of Eastern Canada as related to soil temperature and depth

2 Statistical questions

In addition to data exploration, this notebook will answer the following statistical questions.

1. What is the influence of soil depth and temperature on CO2 emission?
2. Can Arrhenius equation and Q10 be useful to describe temperature sensitivity of carbon decomposition across layers?

3 Packages

We need package tidyverse which loads a set of packages for easy data manipulation(Ex: dplyr) and visualization (ex: ggplot2). We also use ggpubr to customise publication ready plot, ggpmisc and grid are useful packages as extensions to ggplot2.

4 Import data

We load two data `data_pot` and `data_co2` involved in our anylisis. `data_pot` contained details about sites sampling, soil sampling(soil depth, weight, water content and bulk density), laboratory incubation temperature while `data_co2` contained details about laboratory incubation time, co2 emission and jar masson details. `data_co2` was combined with `data_pot` with `left_join` function

```
## # A tibble: 72 x 12
##    ID po~1 Sites Depth~2 Repet~3 Tempe~4 Pot w~5 Soil ~6 Water~7 Water~8 Bulk ~9
##      <dbl> <chr>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
##  1       6 A9         10       1      10    245.    110.    42.1    10.3    0.89
##  2      21 A9         10       1      20    251.    110.    42.1    10.3    0.89
##  3      54 A9         10       1      30    250.    110.    42.1    10.3    0.89
##  4      18 A9         10       2      10    246.    125.    27.5    24.9    0.89
##  5      59 A9         10       2      20    248.    125.    27.5    24.9    0.89
##  6      60 A9         10       2      30    255.    125.    27.5    24.9    0.89
##  7      41 A9         10       3      20    248.    117.    35.5    16.9    0.89
##  8      55 A9         10       3      10    249.    117.    35.5    16.9    0.89
##  9      61 A9         10       3      30    249.    117.    35.5    16.9    0.89
## 10      20 A9         10       4      10    245.    123.    28.7    23.7    0.89
## # ... with 62 more rows, 2 more variables: `Carbone(%)` <dbl>, pHCaCl2 <dbl>,
## #   and abbreviated variable names 1: `ID pot`, 2: `Depth (cm)`, 3: Repetition,
## #   4: `Temperature (°C)`, 5: `Pot weight (g)`, 6: `Soil weight (g)`,
## #   7: `Water volume (ml)`, 8: `Water content (%)`, 9: `Bulk density (g/cm3)`
```

5 Some calculations

Several variables have been added to our data in order to proceed for analysis. The added variables are the following: `Temperature (Kelvin)`, `Molar Volume (L/mol)`, `Headspace Volume (mL)`, `Dry soil weight (g)`, `CO2 emission (ug/h/g)`, `CO2 emission (mg/kg)`, `decomposition rate K`, `lnK`and `1/T(T = Temperature(Kelvin)`

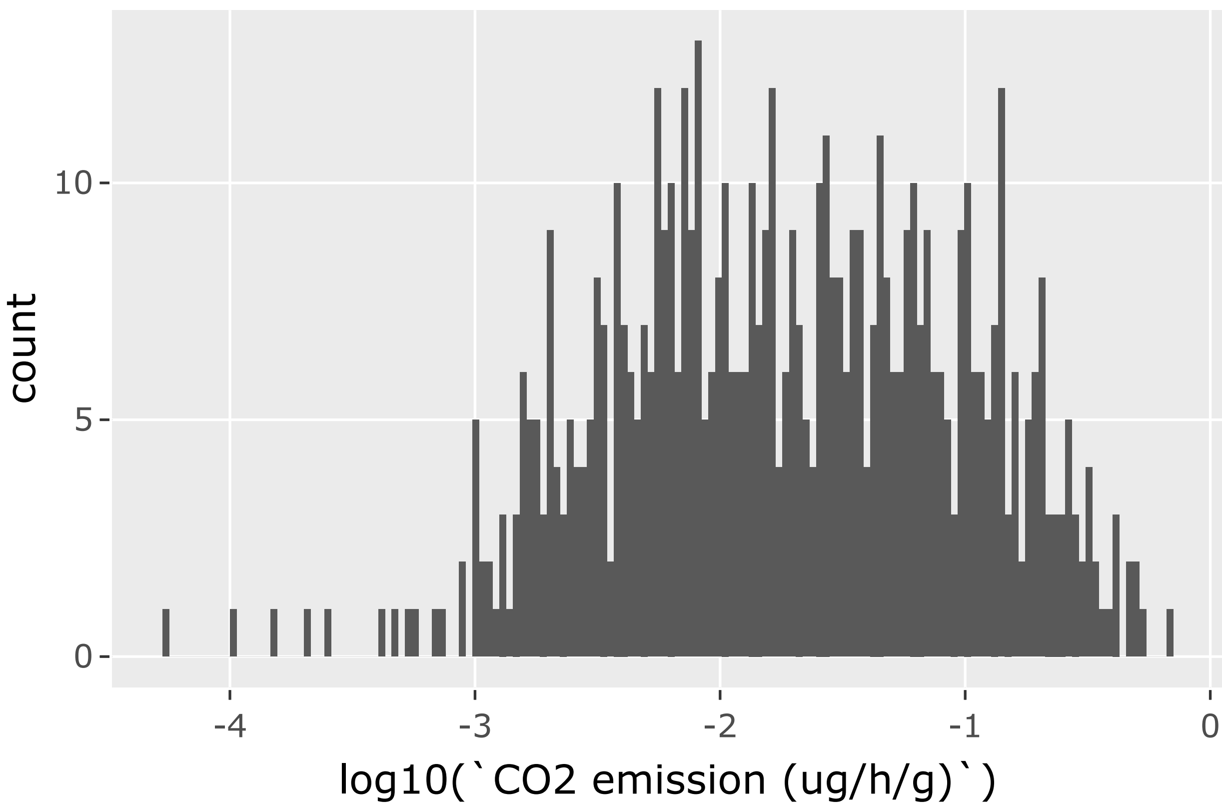
6 Exploratory data analysis

6.1 Histogram

```
New.labs <- c("10°C", "20°C", "30°C") # Change labels
names(New.labs) <- c("10", "20", "30")

New.labs_b <-  c("[0-10 cm]", "[10-20 cm]", "[20-30 cm]") # Change labels
names(New.labs_b) <- c("10", "20", "30")
```

```
library(plotly)
ggplotly(
  data_co2 |>
    ggplot() +
    geom_histogram(aes(x = log10(`CO2 emission (ug/h/g)`)), bins = 150)
)
```

```
## Warning in FUN(X[[i]], ...): NaNs produced

## Warning in FUN(X[[i]], ...): NaNs produced

## Warning: Removed 37 rows containing non-finite values (`stat_bin()`).
```



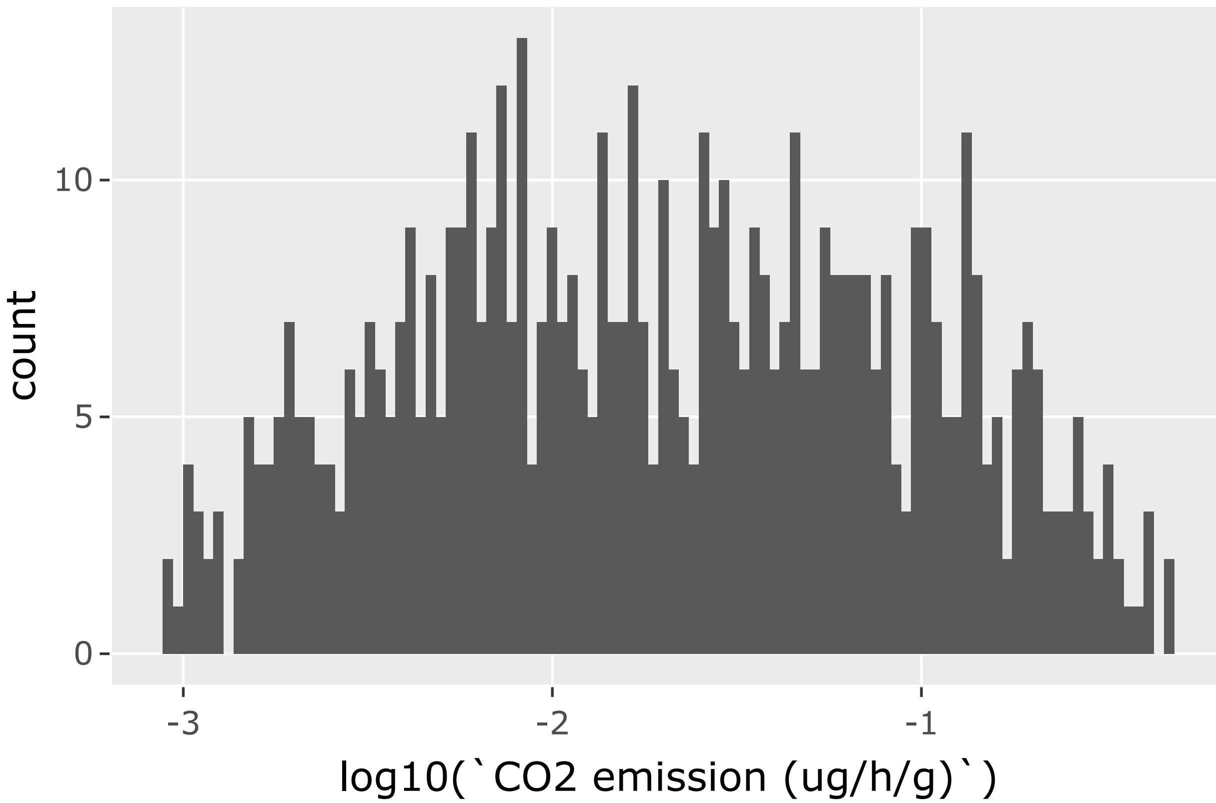
Data contains some outliers, let remove them

```
data_co2_clean <- data_co2 |>
  mutate(log_tr = log10(`CO2 emission (ug/h/g)`)) |>
  filter(log_tr > -3.06 & log_tr < -0.33) |>
  drop_na()
```

```
## Warning in mask$eval_all_mutate(quo): NaNs produced
```

Now data look well distributed

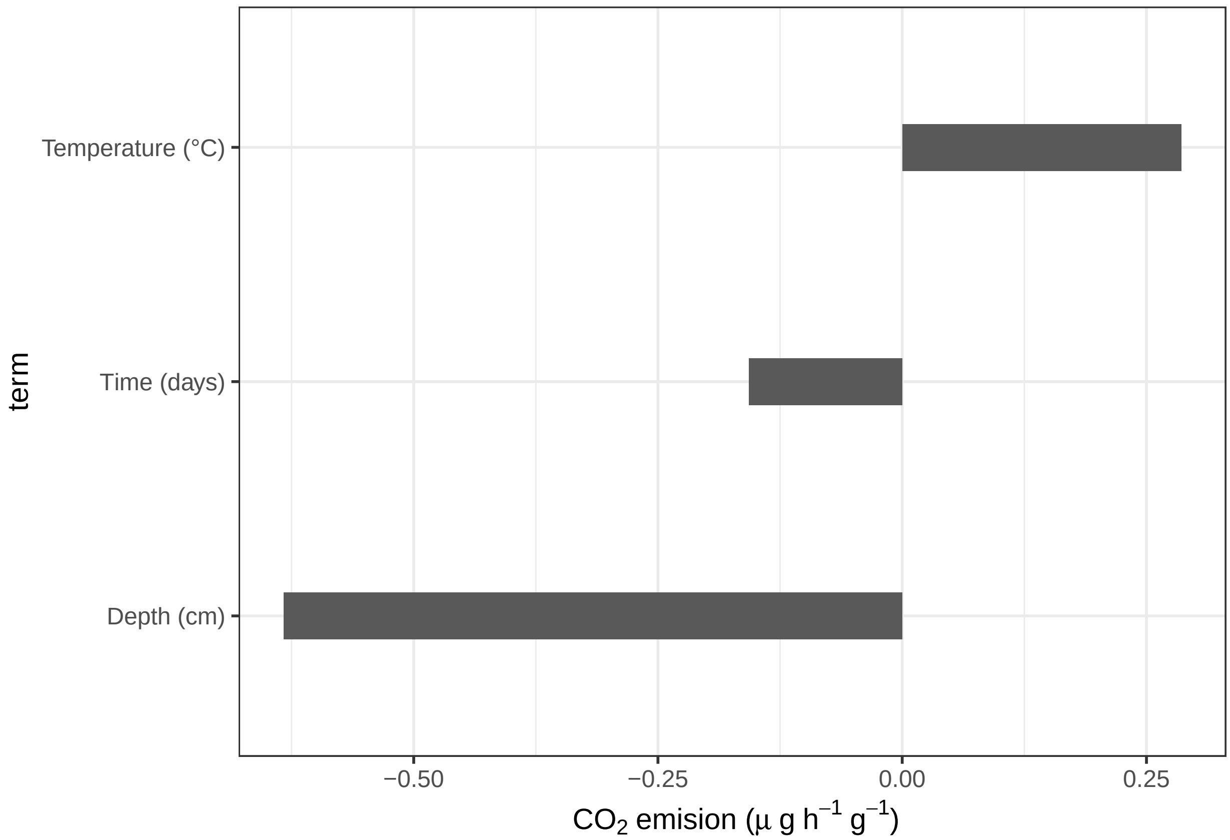
```
ggplotly(
  data_co2_clean |>
    ggplot() +
    geom_histogram(aes(x = log10(`CO2 emission (ug/h/g)`)), bins = 100)
)
```



6.2 Correlations

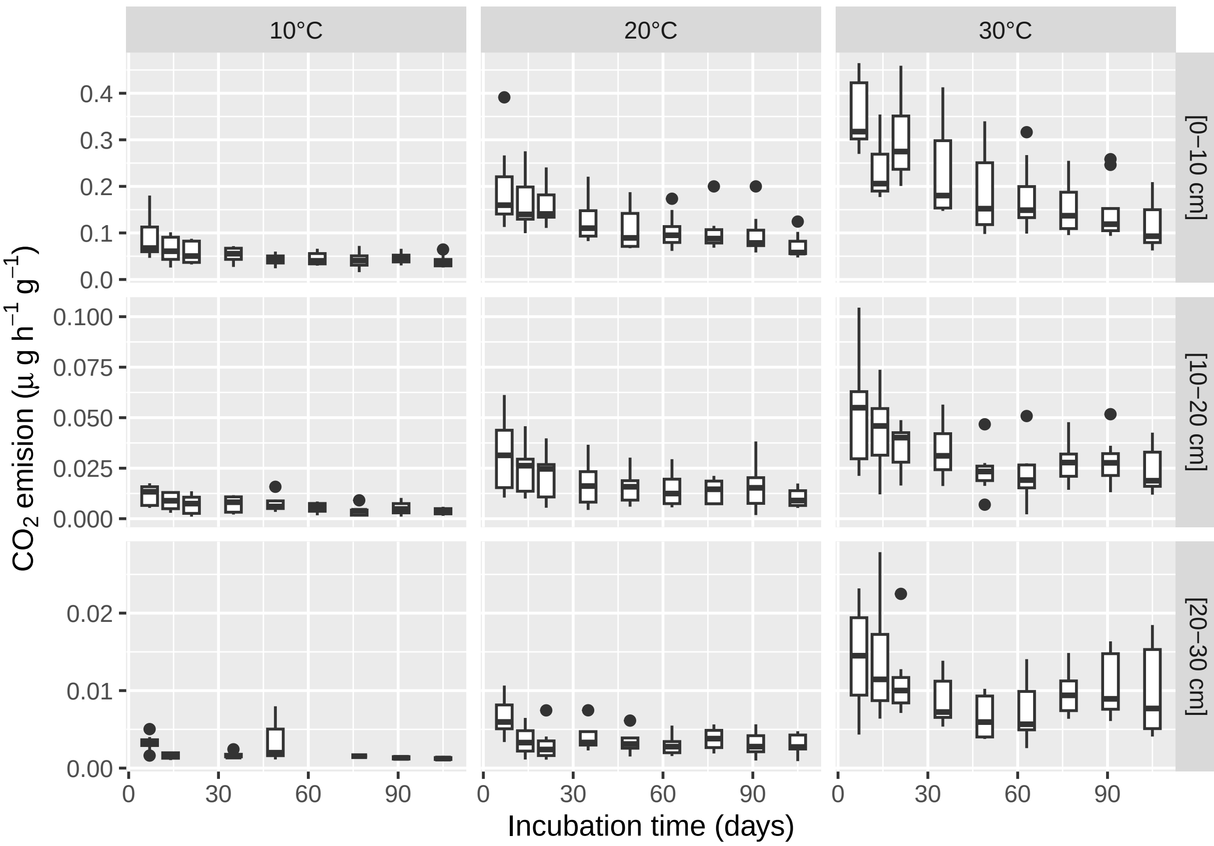
```
data_co2_clean |>
  select(`Time (days)`, `Depth (cm)`, `Temperature (°C)`,
         `CO2 emission (ug/h/g)`) |>
  corrr::correlate() |>
  corrr::focus(`CO2 emission (ug/h/g)`) |>
  mutate(term = fct_reorder(term, `CO2 emission (ug/h/g)`)) |>
  ggplot(aes(x = `CO2 emission (ug/h/g)`, y= term)) +
  geom_col(width = 0.2) +
  labs(x = bquote(~CO[2]~ 'emision ('*mu~'g'~ h^-1~g^-1*')')) +
  theme_bw()
```

```
## Correlation computed with
## * Method: 'pearson'
## * Missing treated using: 'pairwise.complete.obs'
```



6.3 Boxplot

```
options(repr.plot.width = 6, repr.plot.height = 7)
pg <- ggplot(data=data_co2_clean, aes(x = `Time (days)`,
                                      y = `CO2 emission (ug/h/g)` )) +
  geom_boxplot(aes(group = factor(`Time (days)`))) +
  facet_grid(`Depth (cm)` ~ `Temperature (°C)`,   scales = "free",
             labeller = labeller(`Depth (cm)` = New.labs_b,
                                 `Temperature (°C)` = New.labs))+
  labs(x = "Incubation time (days)", y = bquote(~CO[2]~
                                    'emision ('*mu~'g'~ h^-1~g^-1*')'))
pg
```




```
ggsave("figures/Boxplot.png", width = 6, height = 7, dpi = 600)
```

7 What is the influence of soil depth and temperature on CO2 emission?

7.1 Build model: linear regression

```
model_rec <-  data_co2_clean |>
  recipe(`CO2 emission (ug/h/g)` ~ ., data_co2) |>
  step_select(`CO2 emission (ug/h/g)`, `Time (days)`, Sites,
              `Depth (cm)`, `Temperature (°C)`) |>
  step_log(all_outcomes(), base = 10) |>
  step_dummy(Sites) |>
  step_normalize(all_numeric(), -all_outcomes() ) |>
  prep()

data_co2_preprocessed <-  juice(model_rec)
model_spec <- linear_reg() |>
  set_engine("lm")
```

7.1.1 Fit model

```
model_fit <- model_spec |>
  fit(`CO2 emission (ug/h/g)` ~ ., data_co2_preprocessed)
```

7.1.2 Exploring model results

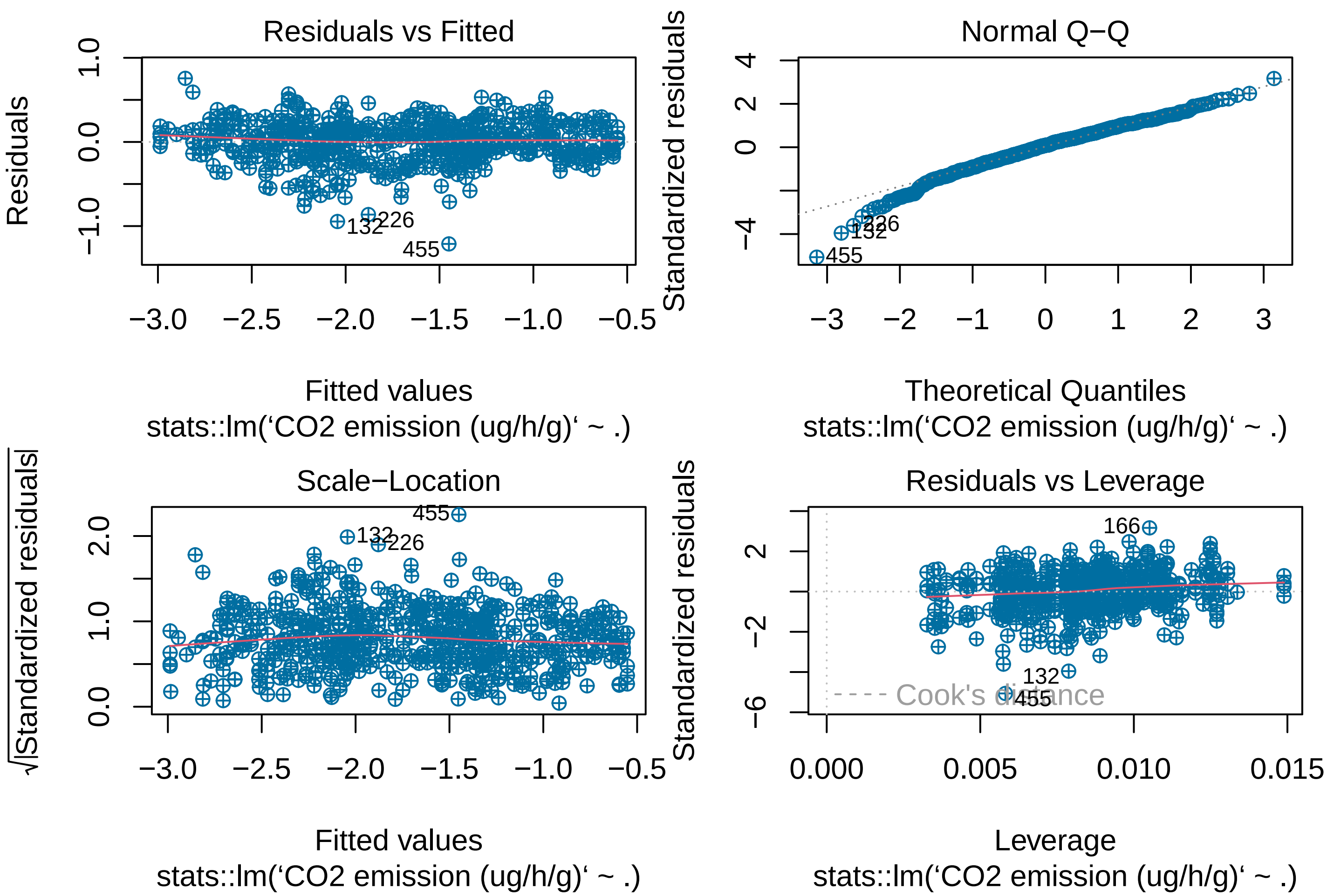
```
tidy(model_fit) |>
  kableExtra::kable()
```

term	estimate	std.error	statistic	p.value
(Intercept)	-1.7027083	0.0098312	-173.193777	0.0000000
‘Time (days)‘	-0.1031241	0.0098514	-10.467956	0.0000000
‘Depth (cm)‘	-0.5785889	0.0099251	-58.295368	0.0000000
‘Temperature (°C)‘	0.2734538	0.0099223	27.559585	0.0000000
Sites_PF45	-0.0201526	0.0098450	-2.046996	0.0411002

```
glance(model_fit)|>
  kableExtra::kable()
```

r.squared	adj.r.squared	sigma	statistic	p.value	df	logLik	AIC	BIC	deviance	df.residual
0.8677052	0.8668098	0.240011	969.074	0	4	7.357261	-2.714521	23.62692	34.04471	591

7.1.3 Inspect the model



7.1.4 Prediction

```
prediction <-  model_fit |>
  predict(data_co2_preprocessed)
```

7.1.5 collect Metrics

```
rmse <-  data_co2_preprocessed |>
  bind_cols(prediction) |>
  rmse(`CO2 emission (ug/h/g)`, .pred)
rmse |>
  kableExtra::kable()
```

.metric	.estimator	.estimate
rmse	standard	0.2390021

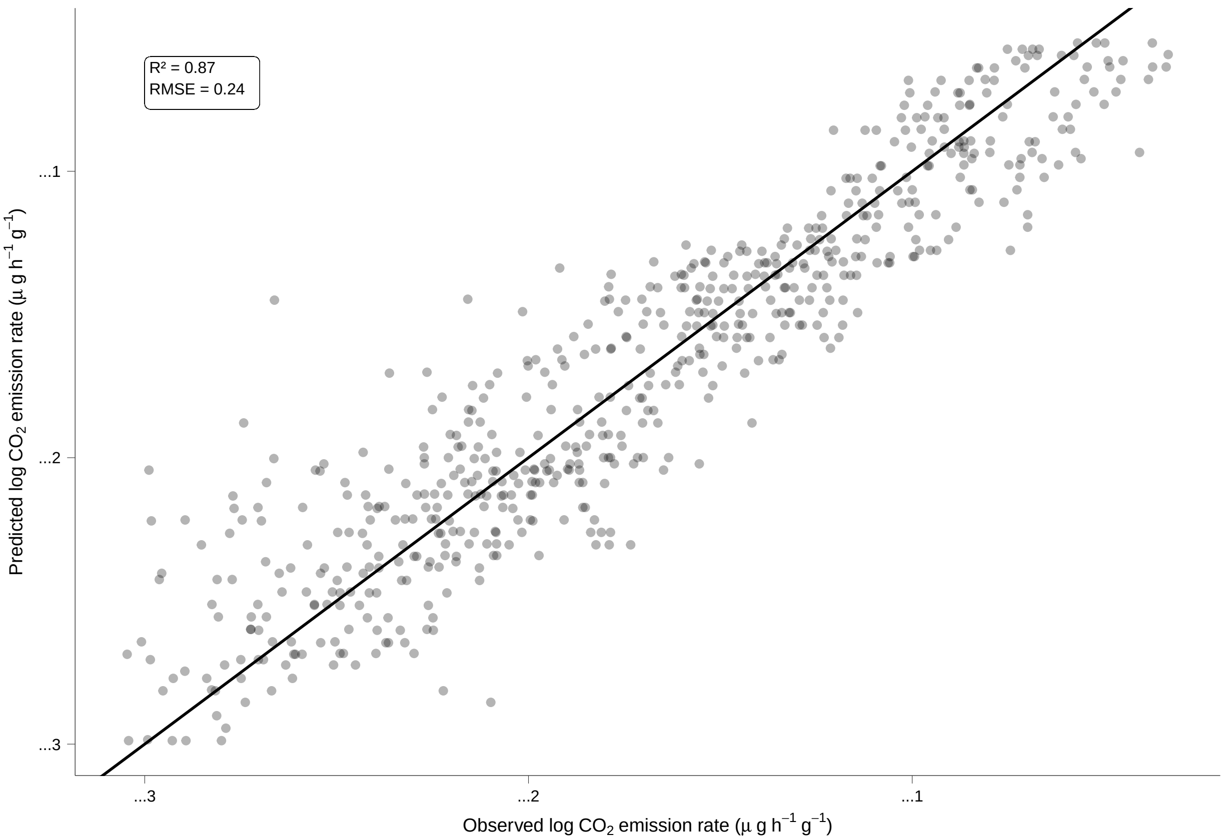
```
rmse <-  round(as.numeric(rmse[1,3]), 2)
```

```
rsq <-  data_co2_preprocessed |>
  bind_cols(prediction) |>
  rsq(`CO2 emission (ug/h/g)`, .pred)
rsq |>
  kableExtra::kable()
```

.metric	.estimator	.estimate
rsq	standard	0.8677052

```
rsq <- round(as.numeric(rsq[1,3]), 2)
```

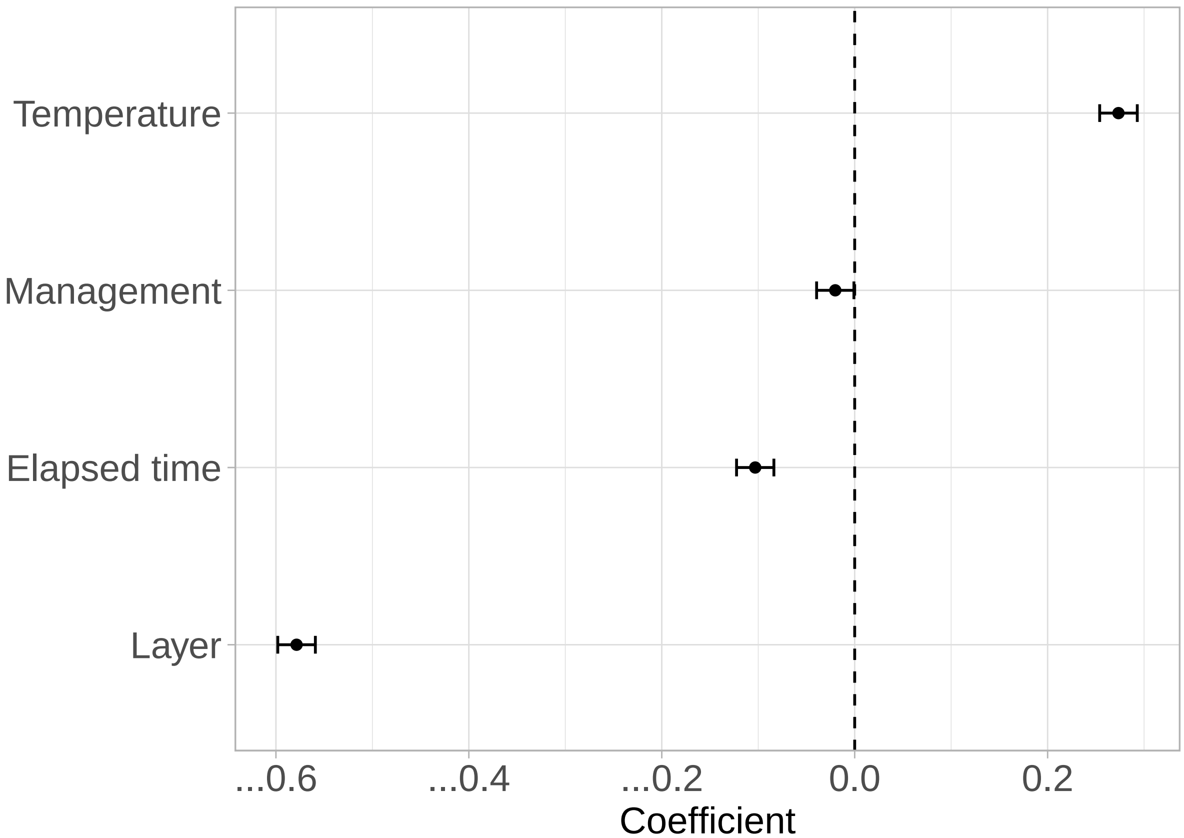
```
options(repr.plot.width = 4, repr.plot.height = 2)
px <- data_co2_preprocessed |>
  bind_cols(prediction) |>
  ggplot(aes(x = `CO2 emission (ug/h/g)`, y = .pred)) +
  geom_point(size = 1, alpha = .3) +
  geom_label(aes(x = -3, y = -.6),
             vjust = 1, hjust = 0, size = 2, label.size = 0.1,
             label = paste("R² =",  rsq, "\nRMSE =", rmse)) +
  geom_abline() +
  scale_x_continuous(breaks = c(-3, -2, -1), labels = c("-3", "-2", "-1")) +
  scale_y_continuous(breaks = c(-3, -2, -1), labels = c("-3", "-2", "-1")) +
  theme_pubr()  +
  theme(axis.title=element_text(size=7),
        axis.line = element_line(size = 0.1),
        axis.ticks = element_line(size = 0.1),
        axis.text = element_text(size = 6)) +
  labs(x= bquote("Observed log"~CO[2]~
                   'emission rate ('*mu~'g'~ h^-1~g^-1*')'),
       y = bquote("Predicted log"~CO[2]~
                    'emission rate ('*mu~'g'~ h^-1~g^-1*')'))
px
```




```
ggsave("figures/Observed and predicted co2 emission.png", width = 4,
       height = 2.5, dpi = 600)
```

7.2 Variable coefficient and confidence intervals

```
options(repr.plot.width = 8, repr.plot.height = 2)
term_rename <- tibble(term = c("`Time (days)`", "`Depth (cm)`",
                               "`Temperature (°C)`", "Sites_PF45"),
                      name_corrected = c("Elapsed time", "Layer", "Temperature", "Management"))

h <- broom::tidy(model_fit, conf.int = TRUE) |>
  dplyr::filter(term != "(Intercept)") |>
  left_join(term_rename, by = "term") |>
  mutate(term_rename = fct_reorder(name_corrected, estimate)) |>
  ggplot(aes(estimate, term_rename)) +
  geom_vline(xintercept = 0, linetype = 2) +
  geom_point() +
  geom_errorbarh(aes(xmin = conf.low, xmax = conf.high), height = 0.1,
               size=0.5) +
  scale_x_continuous(breaks = c(-0.6, -0.4, -0.2, 0.0, 0.2),
                     labels = c("-0.6", "-0.4", "-0.2", "0.0", "0.2")) +
  labs(x = "Coefficient", y = "") +
  theme_light() +
  theme(axis.text=element_text(size=14),
        axis.title=element_text(size=14)) # Time (d)
h
```

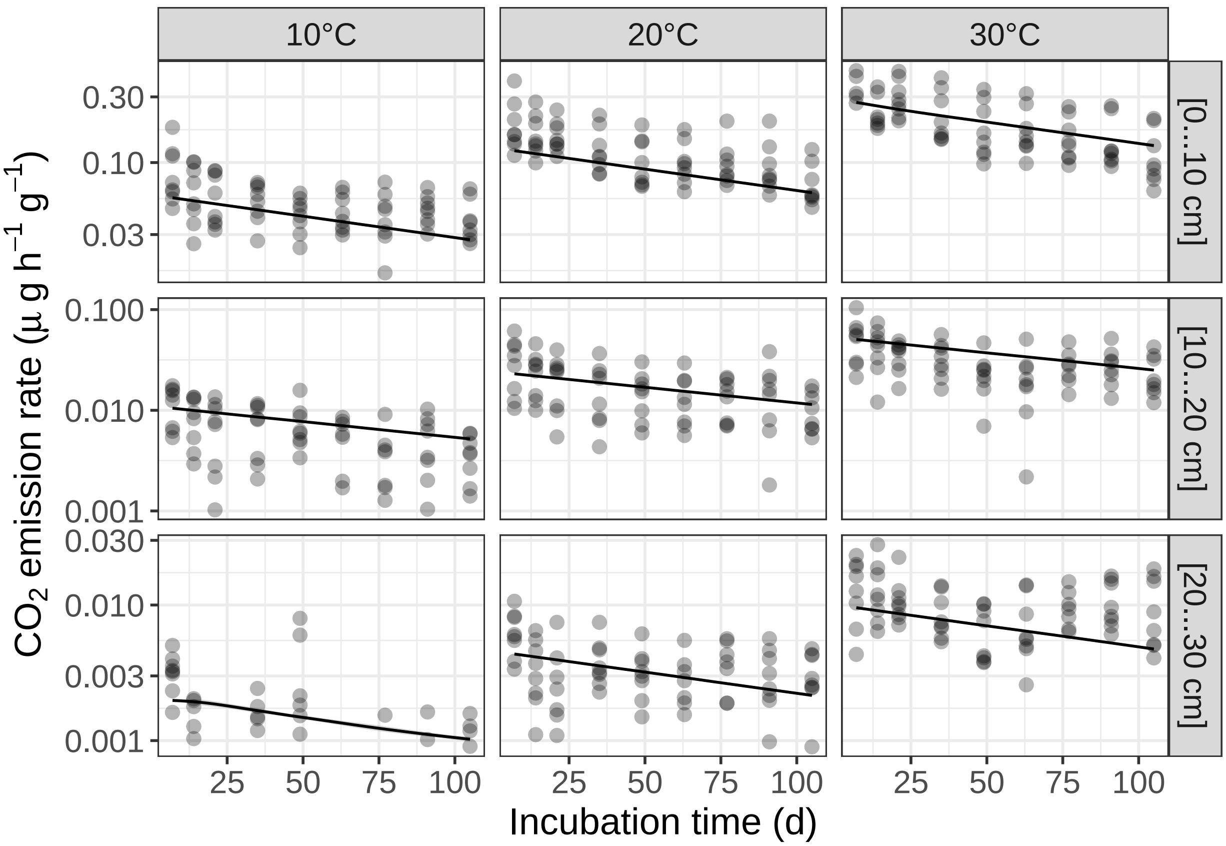



```r
ggsave("figures/Linear-model-Co2_with_site.png", width = 8,
       height = 2, dpi = 600)
```

7.3 Prediction model of CO2 emission in cranberry soils in three-layer positions (0-10 cm, 10-20 cm, 20-30 cm) and at three temperatures (10, 20 and 30oC).

```r
New.labs <- c("10°C", "20°C", "30°C") # Change labels
names(New.labs) <- c("10", "20", "30")

New.labs_b <-  c("[0-10 cm]", "[10-20 cm]", "[20-30 cm]") # Change labels
names(New.labs_b) <- c("10", "20", "30")

options(repr.plot.width = 8, repr.plot.height = 6)
pl <- data_co2_clean |>
  bind_cols(10^prediction) |>
  ggplot(aes(x = `Time (days)`, y = `CO2 emission (ug/h/g)`)) +
  geom_smooth(aes(x = `Time (days)`, y = `.pred`), color = "black", size = .5) +
  geom_point(size = 2, alpha = .3) +
  facet_grid(`Depth (cm)` ~ `Temperature (°C)`, scales = "free",
             labeller = labeller(`Depth (cm)` = New.labs_b,
                                 `Temperature (°C)` = New.labs)) +
  scale_y_log10() +
  theme_bw() +
  theme(strip.text = element_text(size = 12), axis.text=element_text(size=12),
        axis.title=element_text(size=14),
        axis.title.y = element_text(size=14)) +
```

```
  xlab("Incubation time (d)") + ylab(bquote(~CO[2]~ 'emission rate ('*mu~'g'~ h^-1~g^-1*')'))
pl
```




```
ggsave("figures/CO2 emission.png", plot= pl, width = 7, height = 5, dpi = 600)
```

8 What is the temperature sensitivity across cranberry soil layers?

8.1 Fit of Arrhenius equation

The Arrhenius equation has been used to describe temperature sensitivity to CO2 emission. The Arrhenius equation was computed as follows:

$$k = Ae^{\frac{-Ea}{RT}}$$

$$log\left(k\right) = log\left(Ae^{\frac{-Ea}{RT}}\right)$$

$$log\left(k\right) = log\left(A\right) + log\left(e^{\frac{-Ea}{RT}}\right)$$

$$log\left(k\right) = log\left(A\right) - \frac{1}{T} \times \left(\frac{Ea}{R}\right)$$

Where A is the pre-exponential factor and Ea is activation energy assumed to be independent of temperature, R is the universal gas constant and T is absolute temperature (Kelvin)

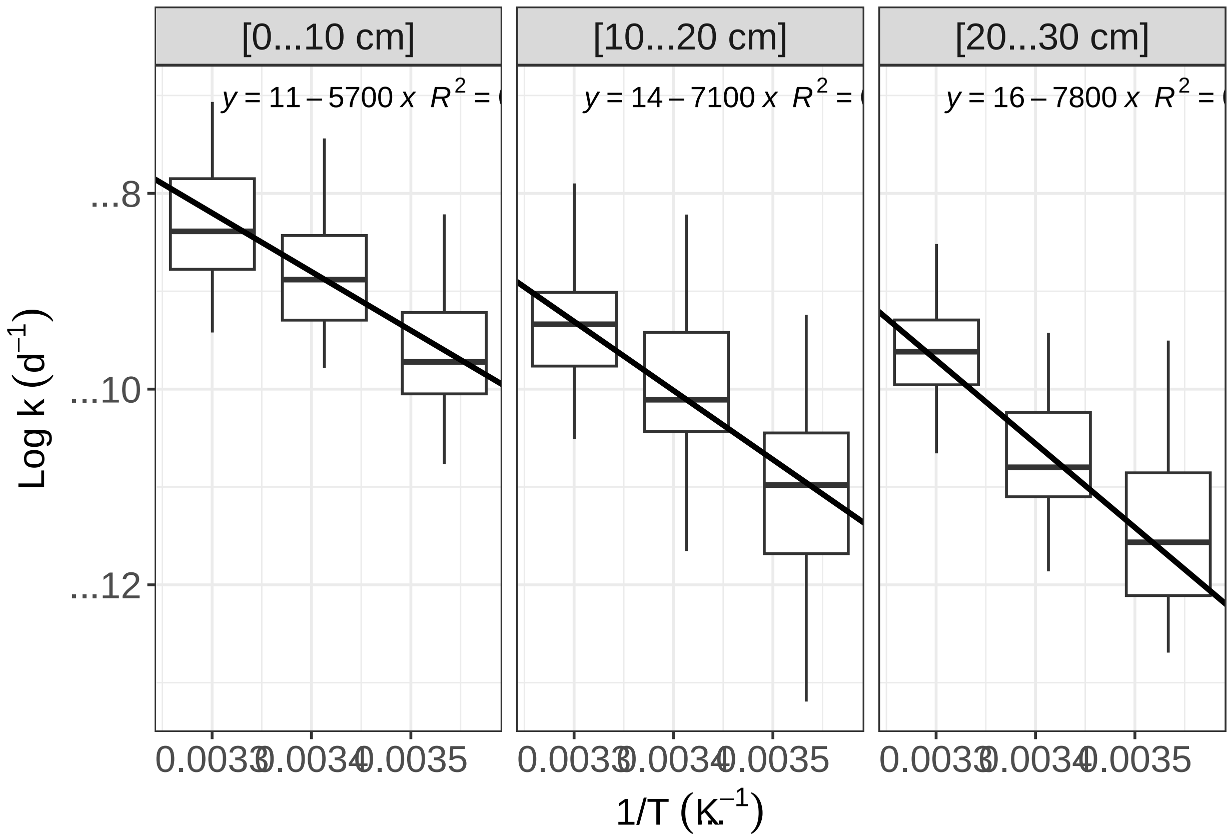
```r
models_co2 <- data_co2 %>%
  group_by(`Depth (cm)`) %>%
  summarise(linmod = list(lm(lnK ~ `1/T`)))
models_co2
```

```
## # A tibble: 3 x 2
##   `Depth (cm)` linmod
##          <dbl> <list>
## 1           10 <lm>
## 2           20 <lm>
## 3           30 <lm>
```

```r
linmod_coef <- list()
for (i in seq_along(models_co2$linmod)) linmod_coef[[i]] <- models_co2$linmod[[i]]$coefficients
linmod_coef <- do.call(rbind.data.frame, linmod_coef)
names(linmod_coef) <- c("Intercept", "Slope")
linmod_coef <- bind_cols(unique(data_co2["Depth (cm)"]), linmod_coef)
linmod_coef |>
  kableExtra::kable()
```

Depth (cm)	Intercept	Slope
10	11.60517	-6001.720
20	13.96191	-7052.007
30	18.53837	-8557.755

```r
options(repr.plot.width = 12, repr.plot.height = 6)
plot_co2 <- data_co2_clean %>%
  ggplot(aes(x = `1/T`, y = lnK)) +
  facet_grid(~`Depth (cm)`, labeller = labeller(`Depth (cm)` = New.labs_b)) +
  geom_boxplot(aes(group = factor(`1/T`)), outlier.shape = NA) +
  stat_regline_equation(aes(label =  paste(..eq.label.., ..rr.label..,
                                                  sep = "~~")), label.x = 0.00331,
                           label.y = -7) +
  geom_abline(data = linmod_coef, aes(intercept = Intercept, slope = Slope),
              lwd = 1) +
  scale_y_continuous(breaks = c(-12, -10, -8), labels = c("-12", "-10", "-8")) +
  labs(x =  bquote("1/T" ~( K^-1)), y = bquote("Log k" ~(d^-1))) +
  theme_bw() +
  theme(strip.text = element_text(size = 14), axis.text=element_text(size=14),
        axis.title=element_text(size=14))
plot_co2
```




```
ggsave("figures/Arrhénius équation.png", plot = plot_co2, width = 8,
       height = 4, dpi = 600)# export plot high resolution
```

8.2 Activation Energy computation

```
Activation_energy <- tibble(
  Soil_layers = c("10", "20", "30"),
  intercept = NA,
  slope = NA,
  adj_r_sq = NA
)
```

```
lm_arrhenius <- for (i in 1:nrow(Activation_energy)) {

  lm_Activation_energy <- data_co2_clean %>%
    filter(`Depth (cm)` == Activation_energy$Soil_layers[i]) %>%
    lm(lnK ~ `1/T`, data = .)

  # intercept
  Activation_energy$intercept[i] <- coef(lm_Activation_energy)[1]

  # Slope
  Activation_energy$slope[i] <- coef(lm_Activation_energy)[2]

  # statistics
  Activation_energy$adj_r_sq[i] <- summary(lm_Activation_energy)$adj.r.squared
}
```

```r
R = 8.3144621 / 1000 # Gas constant Kj/mol/K
Activation_energy <-  Activation_energy %>%
  mutate(Ea = -slope * R) %>%
  select(Soil_layers, adj_r_sq, Ea)
Activation_energy |>
  flextable()
```

Soil_layers	adj_r_sq	Ea
10	0.4770485	47.49089
20	0.4015598	58.63364
30	0.5066868	64.90871

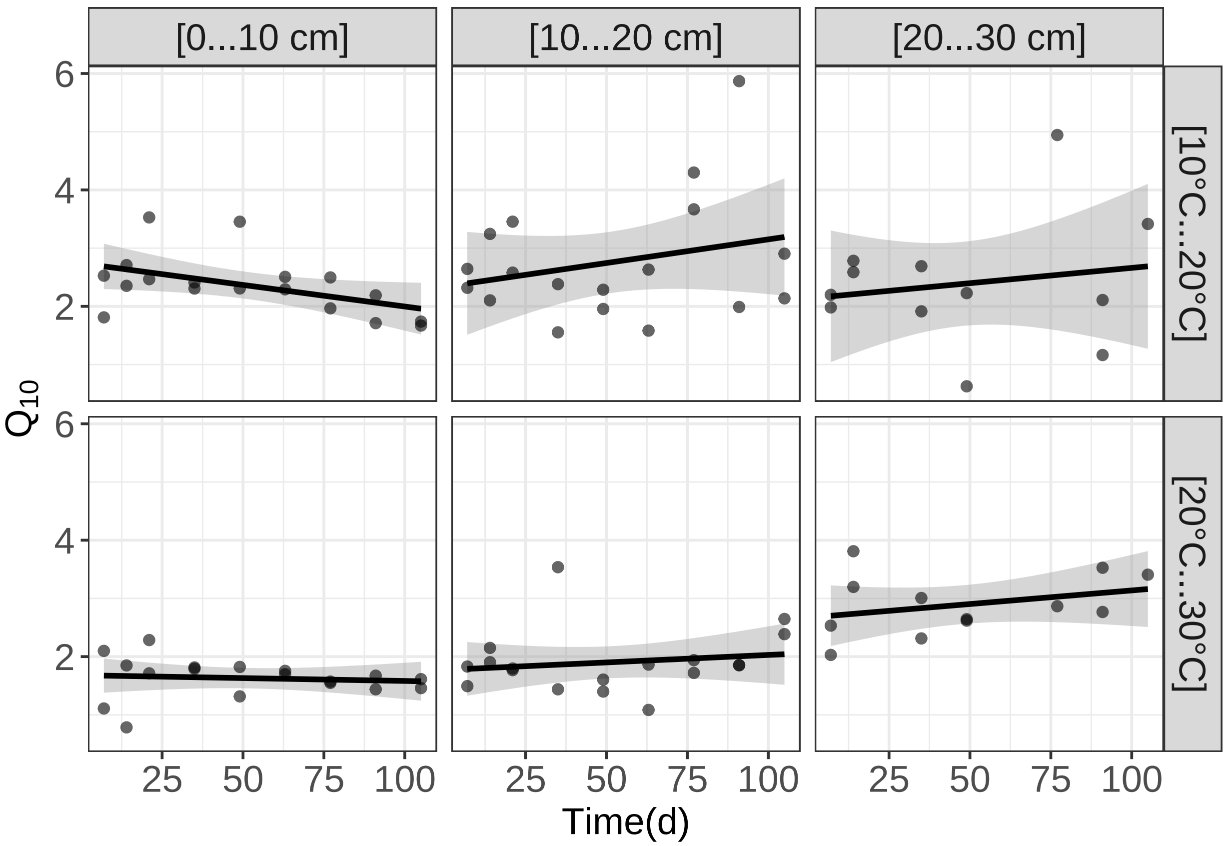
8.3 Computing K median in order to compute Q10 value accross soil depth

```r
K_median <- aggregate(K ~ `Sites` + `Time (days)` + `Depth (cm)` +
                        `Temperature (°C)`, data = data_co2_clean, FUN = median)

K_median <- K_median %>%
  pivot_wider(names_from = `Temperature (°C)`, values_from = K)


K_median$Q_20_10 <- K_median$`20` / K_median$`10`
K_median$Q_30_20 <- K_median$`30` / K_median$`20`

K_median <- K_median %>%
  na.omit(K_median)
data_Q10 <- gather(data = K_median, key = `Temperature range`,
                   value = Q10, c(`Q_20_10`, `Q_30_20`),
                   factor_key=TRUE)

stat_Q10 <- data_Q10 |>
  group_by(`Depth (cm)`) |>
  get_summary_stats(Q10)
stat_Q10 |>
  kableExtra::kable()
```

Depth (cm)	variable	n	min	max	median	q1	q3	iqr	mad	mean	sd	se	ci
10	Q10	36	0.785	3.528	1.818	1.672	2.319	0.647	0.542	1.994	0.568	0.095	0.192
20	Q10	36	1.084	5.869	2.046	1.789	2.634	0.845	0.579	2.330	0.936	0.156	0.317
30	Q10	24	0.627	4.943	2.631	2.175	3.054	0.879	0.709	2.640	0.873	0.178	0.369

```r
New.labs_c <- c("[10°C-20°C]", "[20°C-30°C]") # Change labels
names(New.labs_c) <- c("Q_20_10", "Q_30_20")

options(repr.plot.width = 8, repr.plot.height = 4)
 data_Q10 |>
  mutate(`Layers` = as.character(`Depth (cm)`)) |>
  ggplot(aes(x = `Time (days)`, y = `Q10`)) +
  facet_grid(`Temperature range`~`Depth (cm)`,
```

```
            labeller = labeller(`Depth (cm)` = New.labs_b,
                                `Temperature range` = New.labs_c)) +
  geom_smooth(method = "lm", se = TRUE, color = "Black") +
  geom_point(size = 1.5, alpha = 0.6) +
  labs(x = "Time(d)", y = bquote(Q[10])) +
  theme_bw() +
  theme(strip.text = element_text(size = 14), axis.text=element_text(size=14),
        axis.title=element_text(size=14))
```




```
ggsave("figures/Variation of Q10 across layers.png", width = 8,
       height = 4, dpi = 600)# export plot high resolution
```

9 Soil description

9.1 Soil layers properties

Import data

```
data_carbon_credit <- read_csv2('data/data_carbon_credit.csv')
```

```
## i Using "','" as decimal and "'.'" as grouping mark. Use `read_delim()` for more control.
```

```
## Rows: 24 Columns: 15
## -- Column specification --------------------------------------------------------
## Delimiter: ";"
## chr  (3): Location, Layer (cm), 0_30_ID
## dbl (12): Sample, Site age, Repetition, Bulk density (kg m-3), pHCaCl2, Sand...
##
```

```
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
data_carbon_credit <- data_carbon_credit |>
  mutate(`C:N ratio` = `Carbone (%)` / `Nitrogen (%)`)
```

Some calculations

```
mean_sd_CoverN <- data_carbon_credit |>
  group_by(`Layer (cm)`) |>
  summarize(mean_C_over_N = mean(`C:N ratio`, na.rm = TRUE),
                      se_C_over_N = sd(`C:N ratio`, na.rm = TRUE)/
              sqrt(length(!is.na(`C:N ratio`))))
mean_sd_CoverN
```

```
## # A tibble: 3 x 3
##   `Layer (cm)` mean_C_over_N se_C_over_N
##   <chr>                <dbl>       <dbl>
## 1 [0-10]               20.1         1.05
## 2 [10-20]              16.0         1.91
## 3 [20-30]               9.02        1.96
```

```
data_carbon_credit |> get_summary_stats(`C stock (kg m-3)`)
```

```
## # A tibble: 1 x 13
##   variable        n   min   max median    q1    q3   iqr   mad  mean    sd    se
##   <fct>       <dbl> <dbl> <dbl>  <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1 C stock (k~    24  1.67  30.9   12.5  6.57  16.7  10.1  7.78  12.1  7.05  1.44
## # ... with 1 more variable: ci <dbl>
```

```
data_carbon_credit |>
  group_by(`Layer (cm)`) |>
get_summary_stats(`C stock (kg m-3)`)
```

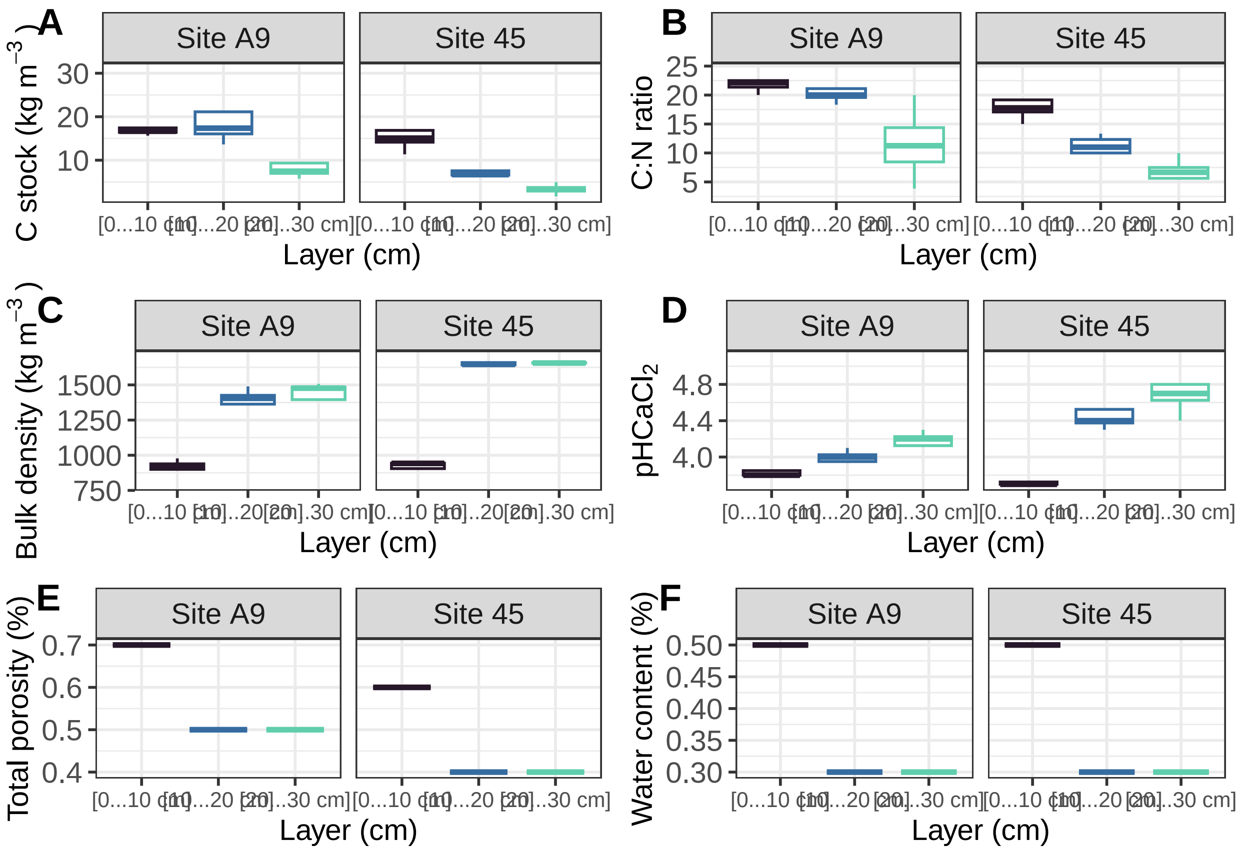
```
## # A tibble: 3 x 14
##   Layer (~1 varia~2     n   min   max median    q1    q3   iqr   mad  mean    sd
##   <chr>     <fct>   <dbl> <dbl> <dbl>  <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1 [0-10]    C stoc~     8 11.4   22.2   16.2  15.1  17.4  2.35  1.60 16.6   3.26
## 2 [10-20]   C stoc~     8  6.52  30.9   11.8   6.74 17.1 10.4   7.62 13.6   8.35
## 3 [20-30]   C stoc~     8  1.67  14.8    5.36  3.31  7.42  4.11  3.04  6.09  4.06
## # ... with 2 more variables: se <dbl>, ci <dbl>, and abbreviated variable names
## #   1: `Layer (cm)`, 2: variable
```

```
data_carbon_credit |>
  group_by(`Layer (cm)`) |>
get_summary_stats(`C:N ratio`) |>
  kableExtra::kable()
```

Layer (cm)	variable	n	min	max	median	q1	q3	iqr	mad	mean	sd	se	ci
[0-10]	C:N ratio	8	15.0	23.333	20.909	17.778	22.500	4.722	2.976	20.088	2.970	1.050	2.483
[10-20]	C:N ratio	8	10.0	24.444	15.833	11.500	20.000	8.500	6.177	16.014	5.397	1.908	4.512
[20-30]	C:N ratio	8	2.5	20.000	8.333	5.962	10.625	4.663	4.324	9.022	5.541	1.959	4.633

```
library(viridis)
plot_desc <- function(y, ylab){
  New.labs_c <-  c("Site A9", "Site 45") # Change labels
```

```r
names(New.labs_c) <- c("Belanger/ A9", "Fortier/ 45")
  ggplot(data_carbon_credit, aes(`Layer (cm)`, y, color = `Layer (cm)`)) +
    geom_boxplot(outlier.shape = NA) +
facet_grid( . ~ `Location`, scales = "free",
            labeller = labeller(`Location` = New.labs_c)) +
    theme_bw() +
    scale_color_viridis_d(option = "G", begin = .1, end = .8) +
    scale_x_discrete(labels = c("[0-10 cm]", "[10-20 cm]", "[20-30 cm]")) +
theme(strip.text = element_text(size = 11), axis.text=element_text(size=11),
      axis.text.x = element_text(size = 8),
        axis.title=element_text(size=11), legend.position = "none") +

    labs(y = ylab)
  }

plot1 <- plot_desc(data_carbon_credit$`C stock (kg m-3)`,
                   bquote("C stock (kg" ~m^-3~")"))
plot2 <- plot_desc(data_carbon_credit$`C:N ratio`, "C:N ratio")
plot3 <- plot_desc(data_carbon_credit$`Bulk density (kg m-3)`, # m-3
                   "Bulk density (kg"~m^-3~")")
plot4 <- plot_desc(data_carbon_credit$pHCaCl2, bquote(pHCaCl[2]))
plot5 <- plot_desc(data_carbon_credit$`Total porosity`, "Total porosity (%)")
plot6 <- plot_desc(data_carbon_credit$`Water content (%)`, "Water content (%)")

options(repr.plot.width = 8, repr.plot.height = 6)
figure <- ggarrange(plot1, plot2, plot3, plot4, plot5, plot6,
                    labels = c("A", "B", "C", "D", "E", "F"), label.x = 0.05,
                    label.y = 1.01,
                    ncol = 2, nrow = 3)
figure
```




```
ggsave("figures/Soil description.png", width = 9, height = 6, dpi = 600)
# export plot high resolution
```

10 C:N ratio in alternate sublayers of sand and organic matter

Data loading

```
Carbon_credit <- read_csv2('data/data_carbon_sublayer.csv')
Carbon_credit |>
  kableExtra::kable()
```

Projet	Site	Horizon	Depht (cm)	Thickness(cm)	Layers	Bulk density(kg m-3)	Soil texture	Site_age	Munsell_
Pedology	Belanger/A9	H1	1.8	1.8	[0-1.8]	912.7	Sand	14	10YR -
Pedology	Belanger/A9	H2	2.2	0.4	[1.8-2.2]	912.7	Organic matter	14	10YR -
Pedology	Belanger/A9	H3	3.2	1.0	[2.2-3.2]	912.7	Sand	14	2,5Y - 5/
Pedology	Belanger/A9	H4	3.6	0.4	[3.2-3.6]	912.7	Organic matter	14	10YR -
Pedology	Belanger/A9	H5	5.1	1.5	[3.6-5.1]	912.7	Sand	14	10YR -
Pedology	Belanger/A9	H6	5.8	0.7	[5.1-5.8]	912.7	Organic matter	14	10YR -
Pedology	Belanger/A9	H7	9.5	3.7	[5.8-9.5]	912.7	Sand	14	2,5Y - 5/
Pedology	Belanger/A9	H8	12.0	2.0	[9.5-12]	1384.4	Organic matter	14	10YR -
Pedology	Belanger/A9	H9	12.5	0.5	[12-12.5]	1384.4	Sand	14	10YR -
Pedology	Belanger/A9	H10	19.2	6.7	[12.5-19.2]	1384.4	Sand	14	10YR -
Pedology	Belanger/A9	H11	27.7	7.7	[19.2-27.7]	1403.0	Sand	14	10YR -
Pedology	Belanger/A9	H11	30.0	2.3	[27.7-30]	1403.0	Sand	14	1,25Y -
Pedology	Fortier/45	H1	2.0	2.0	[0-2]	906.1	Organic matter	19	10YR -
Pedology	Fortier/45	H2	5.0	3.0	[2-5]	906.1	Organic matter	19	7,5YR -
Pedology	Fortier/45	H3	6.1	1.1	[5-6.1]	906.1	Sand	19	2,5Y - 5/
Pedology	Fortier/45	H4	6.4	0.3	[6.1-6.4]	906.1	Organic matter	19	10YR -
Pedology	Fortier/45	H5	7.2	0.8	[6.4-7.2]	906.1	Sand	19	2,5YR -
Pedology	Fortier/45	H6	7.5	0.3	[7.2-7.5]	906.1	Organic matter	19	10YR -
Pedology	Fortier/45	H7	8.6	1.1	[7.5-8.6]	906.1	Sand	19	2,5Y - 4/
Pedology	Fortier/45	H8	8.9	0.3	[8.6-8.9]	906.1	Organic matter	19	2,5Y - 4/
Pedology	Fortier/45	H9	14.8	4.8	[8.9-14.8]	1655.1	Sand	19	2,5Y - 4/
Pedology	Fortier/45	H10	20.0	5.2	[14.8-20]	1655.1	Sand	19	5Y - 5/2
Pedology	Fortier/45	H10	30.0	10.0	[20-30]	1655.1	Sand	19	5Y - 5/2

C:N ratio computation

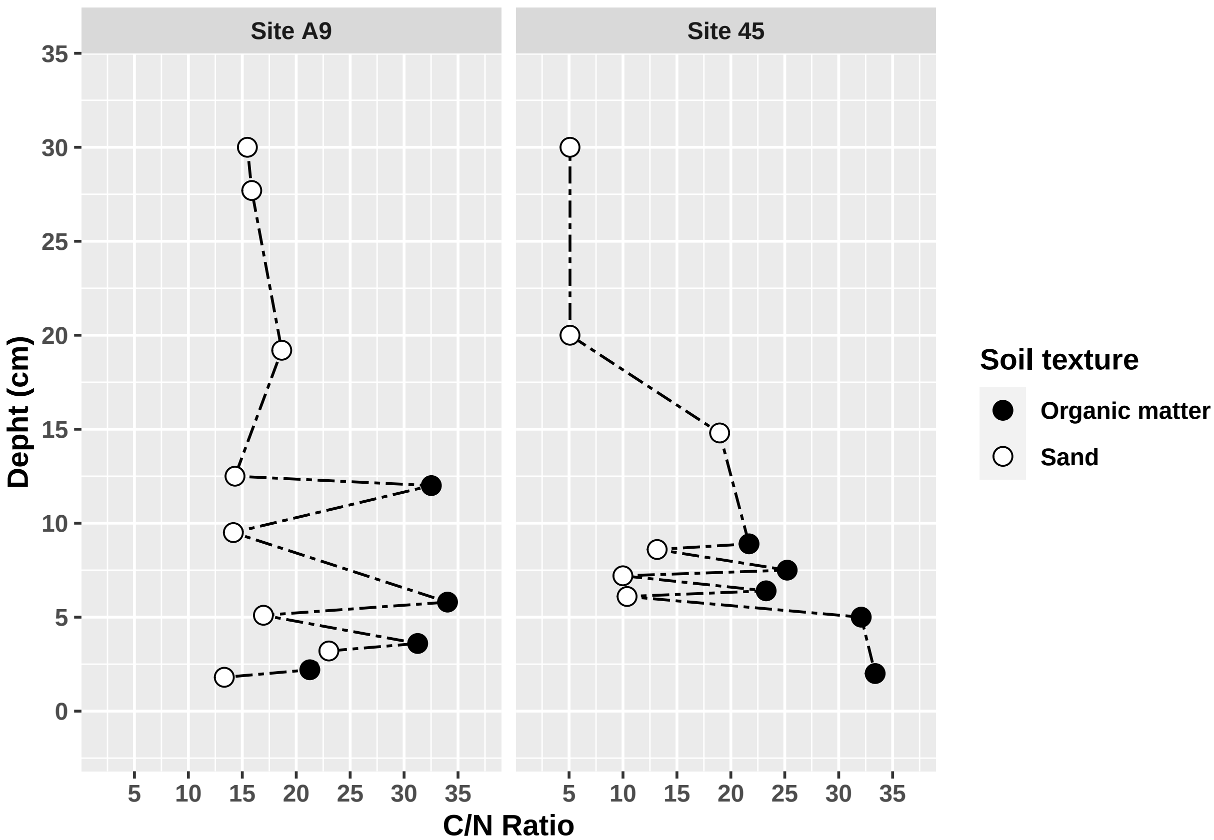
```r
Carbon_credit <- Carbon_credit %>%
mutate(`C/N` = C_pourc/N_pourc)
```

Generating the plots

```r
options(repr.plot.width=8, repr.plot.height=4)
New.labs_d <-  c("Site A9", "Site 45") # Change labels
names(New.labs_d) <- c("Belanger/A9", "Fortier/45")

ggplot(data=Carbon_credit, aes(x= `Depht (cm)`, y= `C/N`)) +
  facet_grid(.~Site, labeller = labeller(`Site` = New.labs_d)) +
  geom_line(linetype = "twodash") +
  geom_point(aes(shape = `Soil texture`, fill = `Soil texture`), size = 3) +
```

```
  scale_shape_manual(values=c(21, 21))+
  scale_fill_manual(values = c("#000000", "#FFFFFF")) +
  scale_y_continuous(breaks = 5*0:1000,
                     expand = expand_scale(add = 5)) +
  scale_x_continuous(breaks = 5*0:1000,
                     expand = expand_scale(add = 5)) +
  theme(strip.text = element_text(face = "bold"),
        axis.text=element_text(face = "bold"),
        axis.title=element_text(face = "bold") ,
        legend.title= element_text(face = "bold"),
        legend.text = element_text(face = "bold")) +
  labs(y= "C/N Ratio") +
  coord_flip()
```

```
## Warning: `expand_scale()` was deprecated in ggplot2 3.3.0.
## i Please use `expansion()` instead.
```




```
ggsave("figures/(C_over_N).png", width = 8, height = 4, dpi = 800)
```