Soil carbon sequestration in a Mediterranean agroforestry system

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Bioemco
Biogéochimie et écologie des milieux continentaux
eco&sols
ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie
FONDATION DE FRANCE
UMR System
AGROOF developpement AGROFORESTERIE

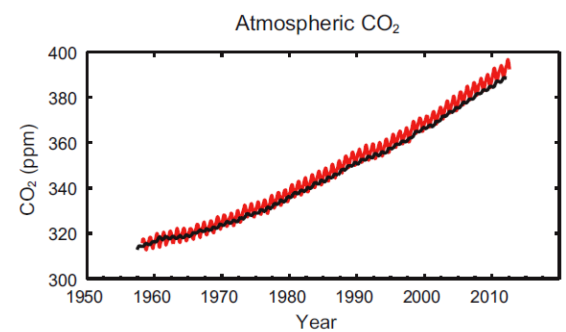
- The soil organic C pool (1550 GT) is **more than 2 times** the size of the atmospheric pool (760 Gt). Soils can act as a source or as a sink of CO_2 (R. Lal, 2004a)

- Since the industrial revolution, depletion of SOC pool have contributed **78 ± 12 Gt of C** to the atmosphere (R. Lal, 2004b)

- One of the main option for GHG mitigation is the **sequestration of carbon in soils** (Hutchinson et al., 2007). Cost competitive and **win–win strategy.**

April 2014: 401.30 ppm
April 2013: 398.35 ppm
Last updated: May 5, 2014

http://www.esrl.noaa.gov/gmd/ccgg/trends/



(IPCC, 2013)

R. Lal, 2004a. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. Science 304:1623-1627.

R. Lal, 2004b. Soil carbon sequestration to mitigate climate change. Geoderma 123: 1–22.

J.J. Hutchinson, C.A. Campbell, R.L. Desjardins, 2007. Some perspectives on carbon sequestration in agriculture. Agricultural and Forest Meteorology 142:288–302

- Agroforestry systems sequester C into both above and belowground biomass

- They could also increase SOC stocks due to higher organic inputs – leaf litter, pruning residues, tree fine root turnover, root exudates

- Have mainly been studied in tropical regions (Albrecht and Kandji, 2003), has mostly concerned superficial soil layers (Lorenz and Lal, 2014)

Agroforest in Cameroon

Faidherbia albida in Burkina Faso

Alain Albrecht, Serigne T. Kandji, 2003. Carbon sequestration in tropical agroforestry systems – Review. Agriculture, Ecosystems and Environment 99: 15–27.

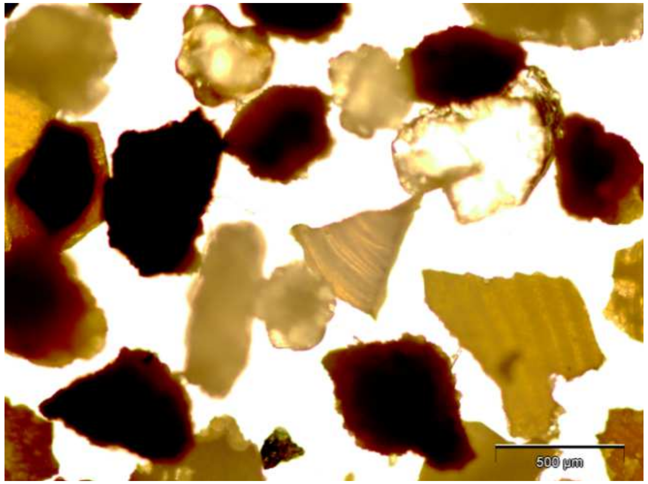
Klaus Lorenz, Rattan Lal, 2014. Soil organic carbon sequestration in agroforestry systems. A review. Agron.omy for Sustainable Development 34: 443-454

➢ Objectives of the study

1. Quantify the SOC stocks down to 2 m soil depth in an 18-year-old agroforestry system and in an adjacent agricultural plot

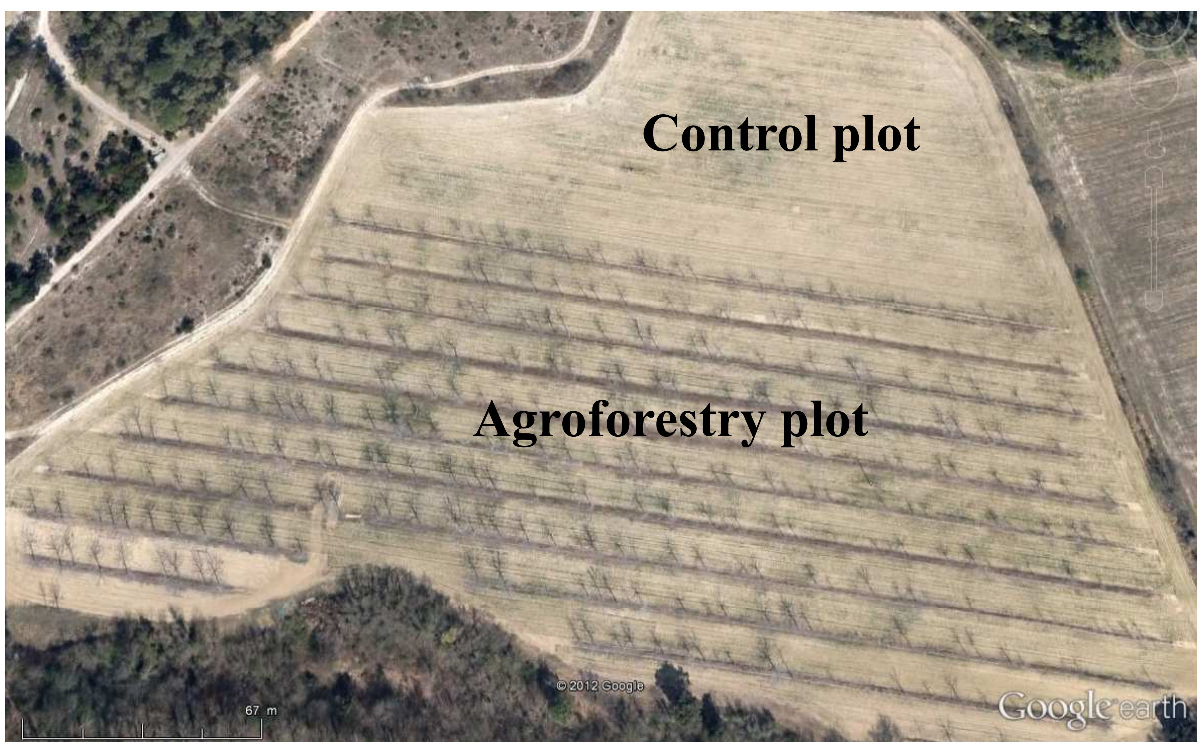
2. Study spatial distribution of SOC stocks in relation to the distance from the trees

3. Assess the form of the possible additional C storage (particulate organic matter, mineral associated C…)



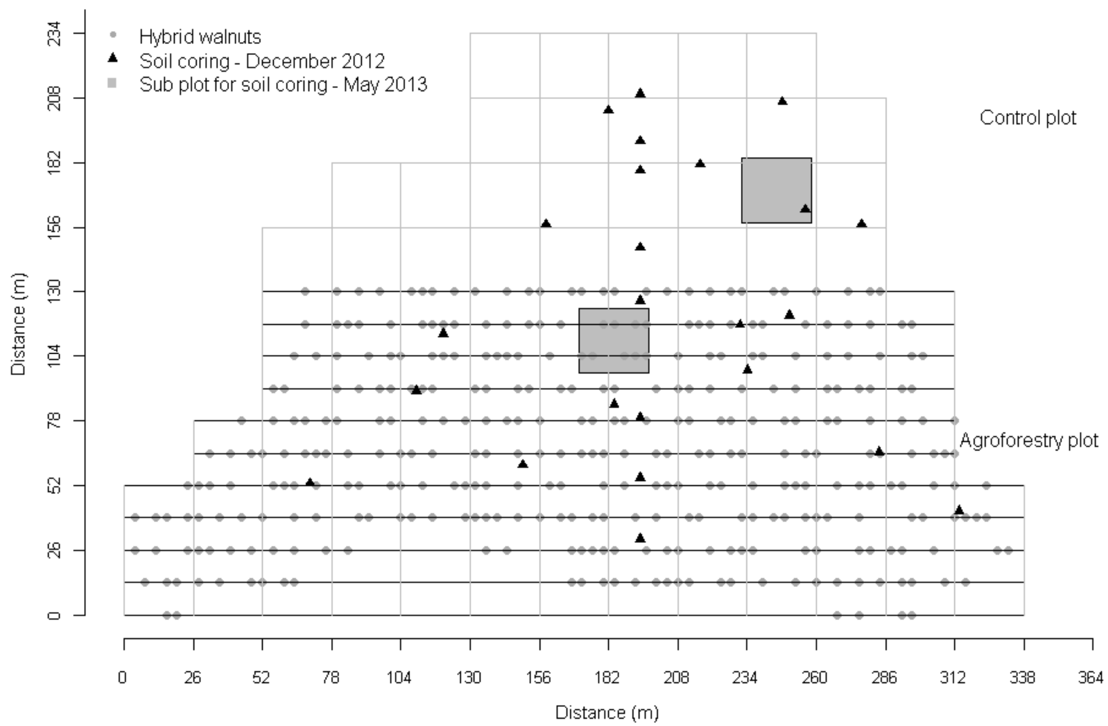
➢ Material and Methods: study site

- Carbonated Fluvisol, near Montpellier, South of France
- In 1995, hybrid walnut trees (*Juglans regia x nigra cv. NG23*) were planted at a density of 110 trees ha^{-1}
- Trees are intercropped with a winter crop, mainly durum wheat (*Triticum turgidum ssp. durum*)



1st field sampling – exploratory
December 2012

→ Study of the spatial variabilty of soil texture



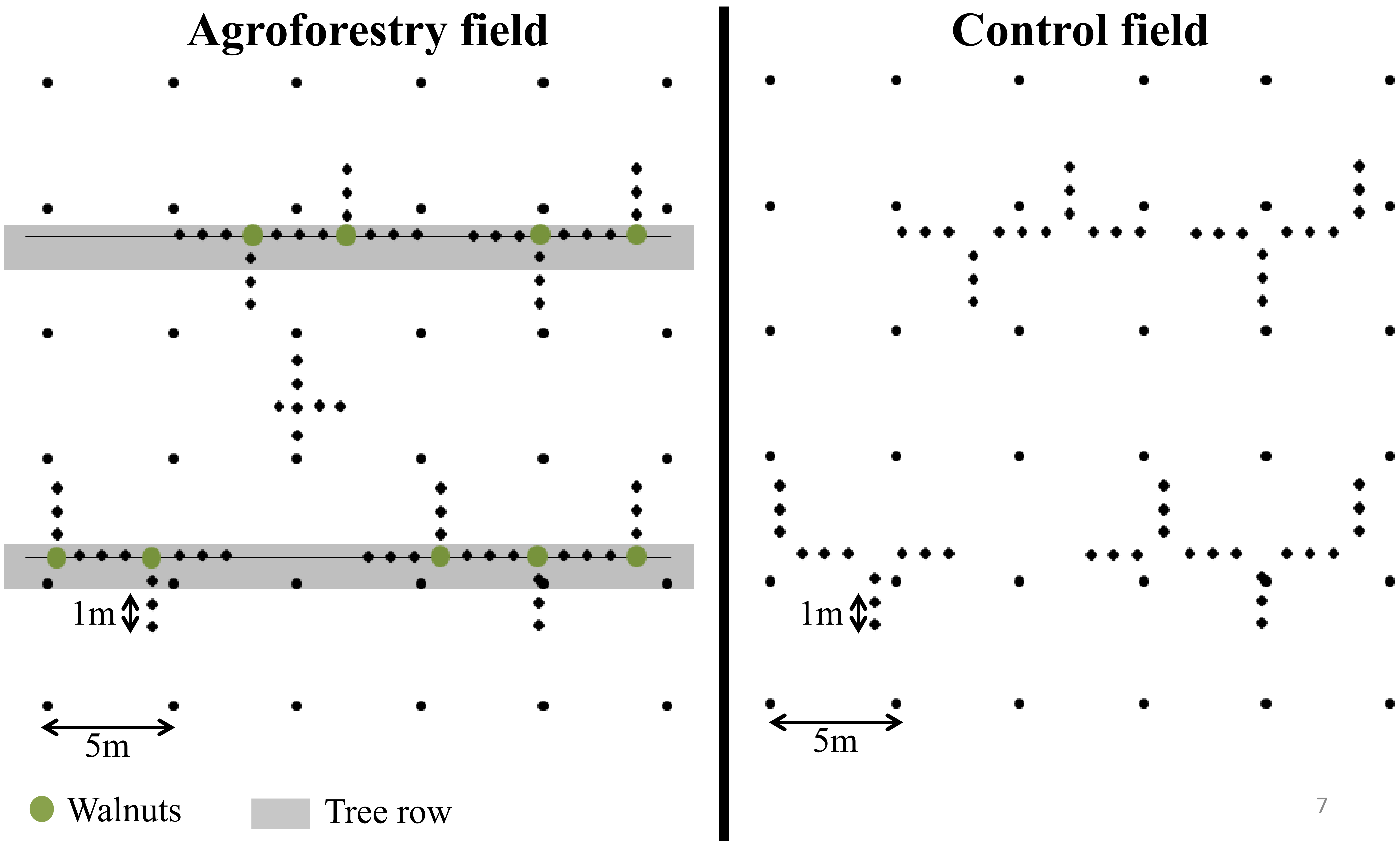
24 soil cores (down to 2 m soil depth)

Field visible and near infrared spectroscopy

2nd field sampling – targeted and intensive
May 2013

→ Focusing on two subplots in the agroforestry and in the control plot with the most similar soil texture

- 100 soil cores were taken in the agroforestry field (40 on the tree row), 93 in the control field, down to 2 m soil depth



➢ Material and Methods: protocole of the 2nd field sampling

Soil coring down to 2m depth (2*1m)

Cutting in 10 sections…

(0-10,10-30,30-50,50-70,70-100,100-120,120-140,140-160,160-180,180-200cm)

… then weighing

➢ Material and Methods: protocole of the 2nd field sampling

Field Vis-NIR spectra (4 per section)
1908 mean spectra

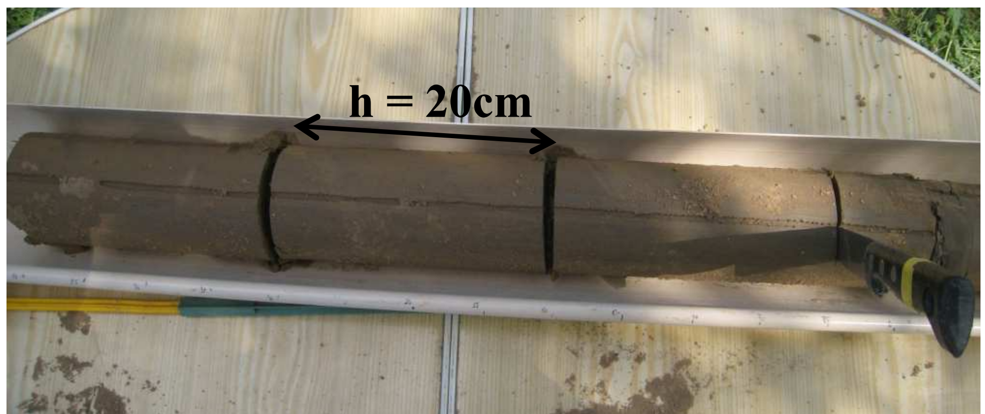
Soil crumbling and sampling of a representative sample - Moistures

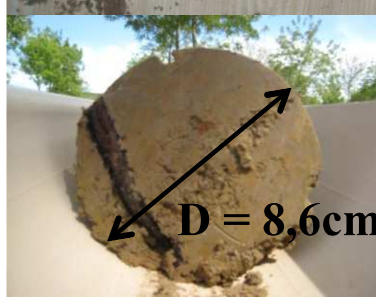
Air drying of 2800 samples and storage

➢ Material and Methods: soil bulk density calculation

Wet mass of soil

Moisture content → **Dry mass of soil**

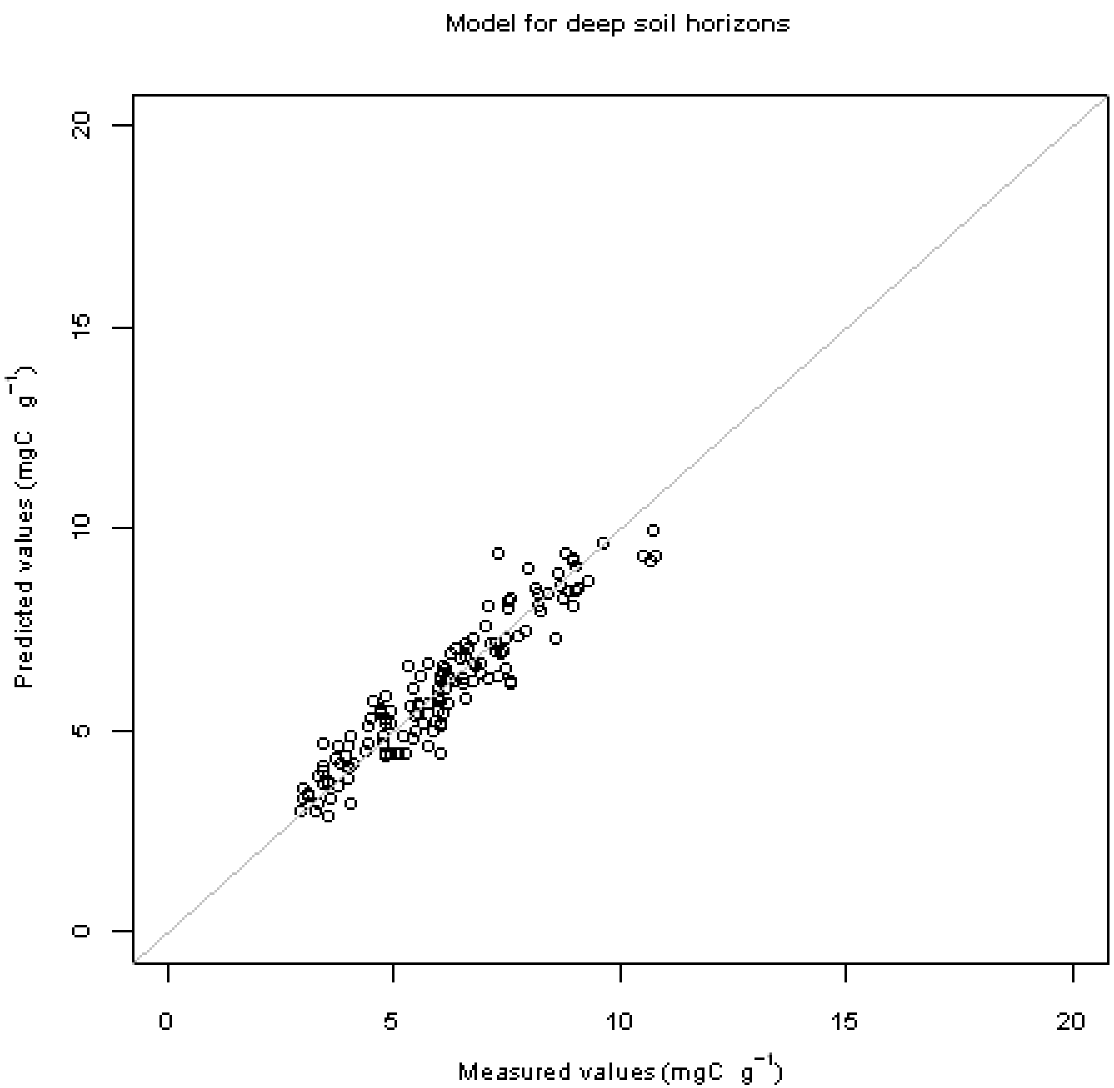




Volume = $\pi.(D^2/4).h$

- SOC stocks were calculated on an equivalent soil mass basis, taking soil bulk densities of the control plot as the reference.

- The model for deep soil horizons was built with 142 reference analyses of SOC

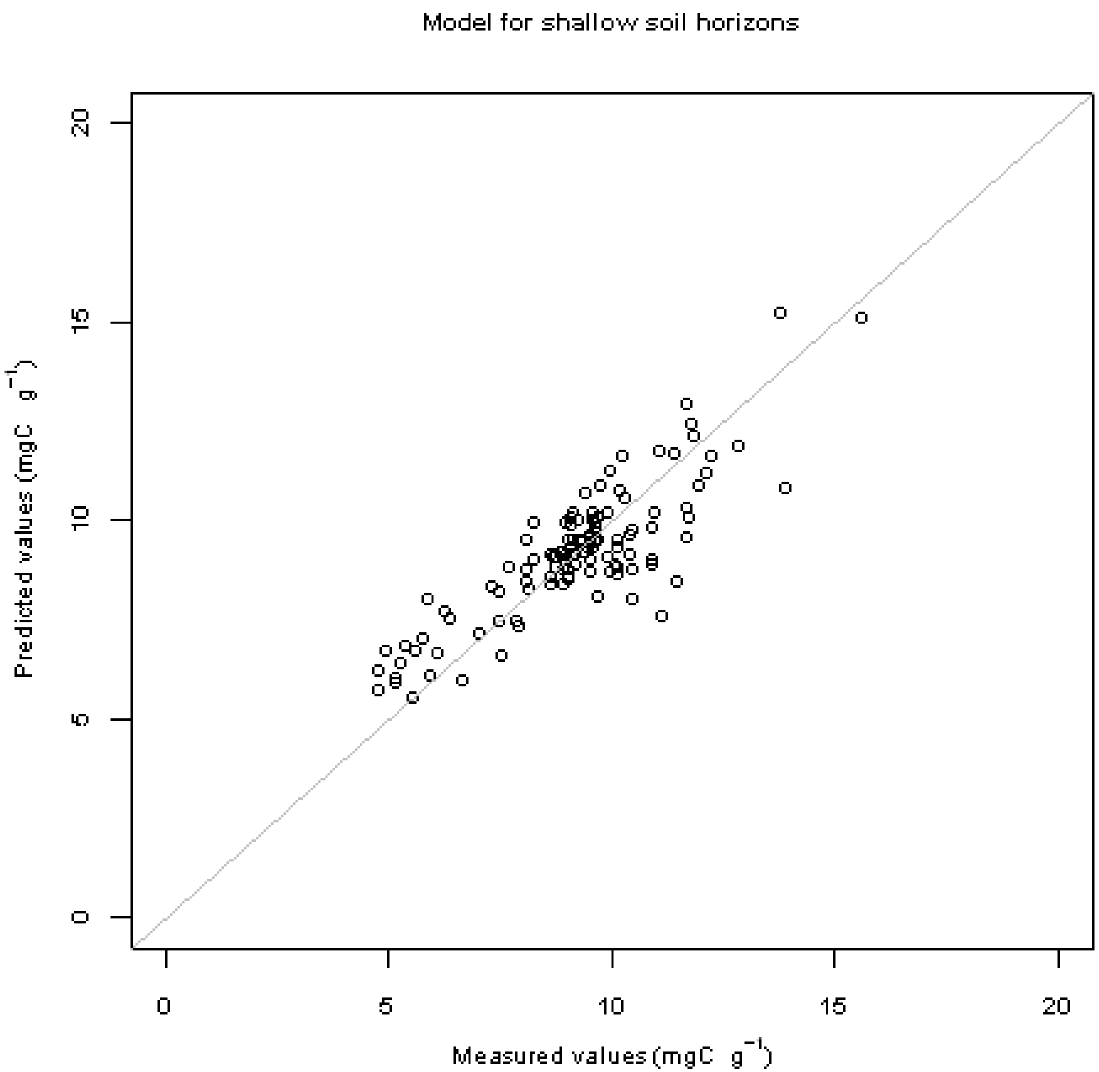


Model for deep soil horizons	
Mean	6.06 mgC g^{-1}
SD	1.86 mgC g^{-1}
RMSEc	0.514 mgC g^{-1}
R^2c	0.9229
RPDc	2.92
R^2cv	0.8252
SEcv	0.774
RPDcv	2.4

$$\text{RPDcv} = \frac{\text{SD}}{SEcv}$$

- The model was used to predict the SOC content of 1380 soil samples. Ratio N analyzed/N predicted = 10.28%

- The model for shallow soil horizons was built with 116 reference analyses of SOC



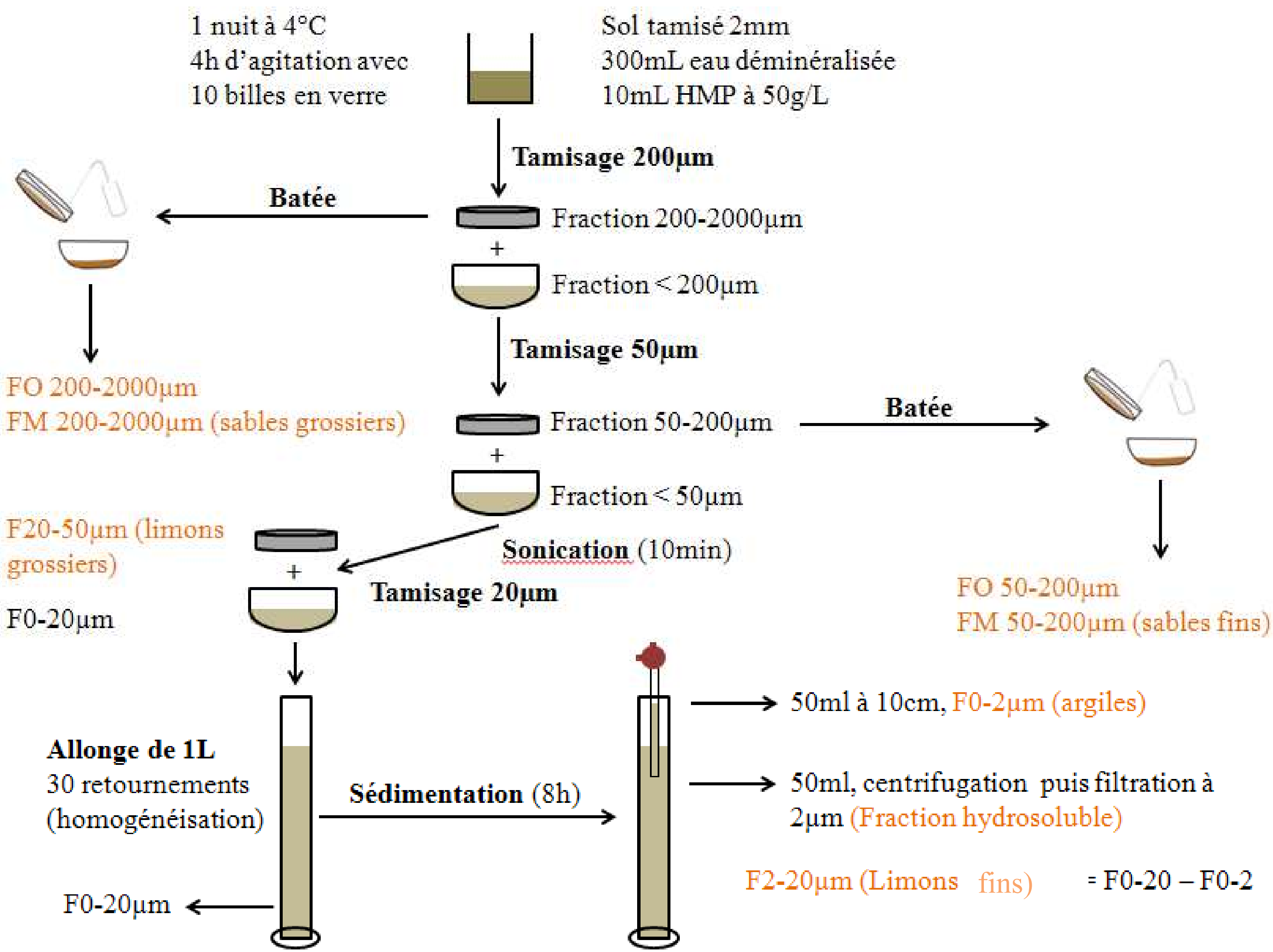
Model for shallow soil horizons	
Mean	9.18 mgC g^{-1}
SD	1.99 mgC g^{-1}
RMSEc	1.057 mgC g^{-1}
R^2c	0.7153
RPDc	1.88
R^2cv	0.6342
SEcv	1.198
RPDcv	1.66

$$RPDcv = \frac{SD}{SEcv}$$

- The model was used to predict the SOC content of 350 soil samples. Ratio N analyzed/N predicted = 44.57%

➢ Material and Methods: soil particle-size fractionation

- **64 soil samples** were particle-size fractionated. 4 depth were studied (0-10cm, 10-30cm, 70-100cm and 160-180cm), on the tree row, on the inter-row and in the control plot



- Mass yield: 98% ; carbon yield: 96%

- Example of one soil core on the tree row

OF>200µm | **Coarse sand** MF>200µm | FO 50-200µm | **Fine sand** MF 50-200µm | **Coarse silt** F20-50µm | **Fine silt + clay** F0-20µm | **Clay** F0-2µm

0-10cm

10-30cm

70-100cm

160-180cm

Material and Methods: soil particle-size fractionation

Grinding of 450 soil fractions

↓

Weighing in silver capsules

↓

Decarbonatation with HCl fumigation

↓

Tin capsules

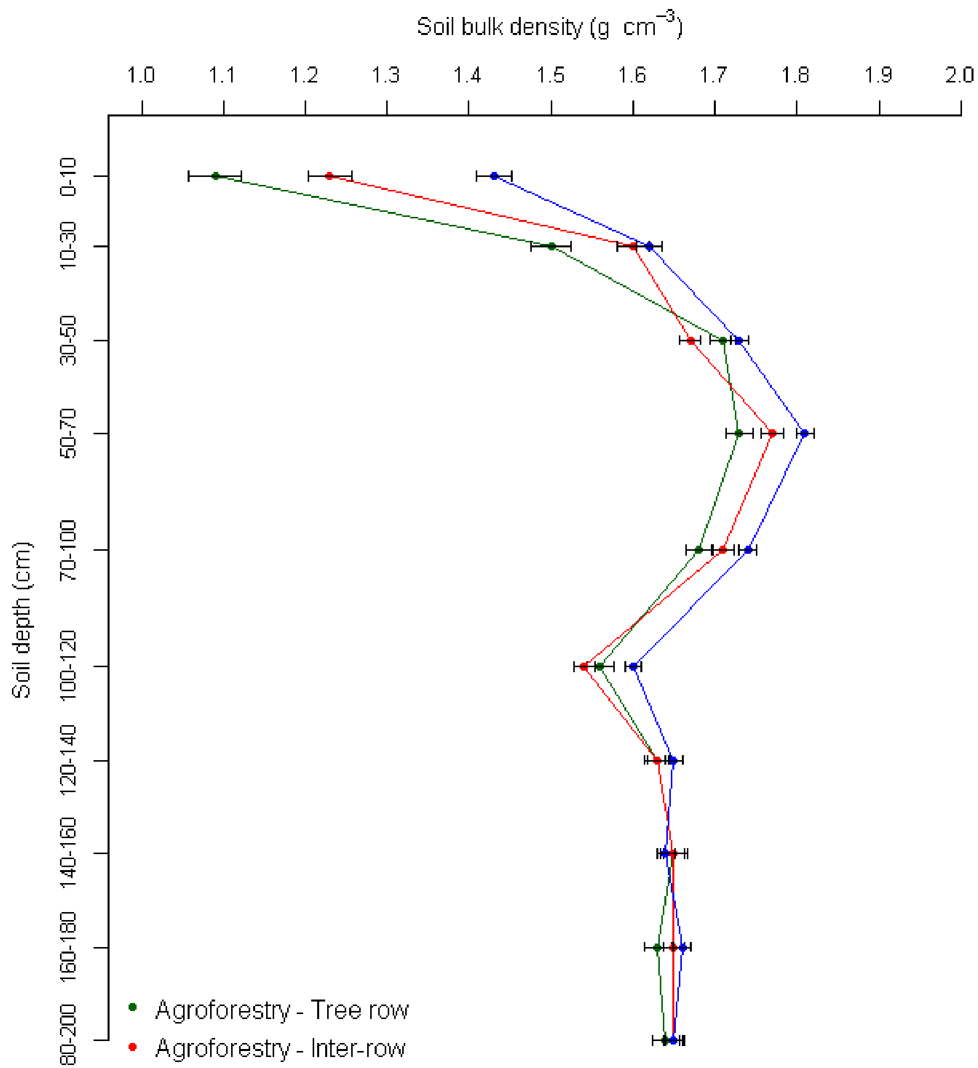
↓

CHN analysis

FO : 4mg
F0-2 et F0-20 : 30mg
F20-50 : 30mg

FM not analyzed (=0 mgC g^{-1})

➢ Results: 1. Quantify the SOC stocks – Soil bulk densities

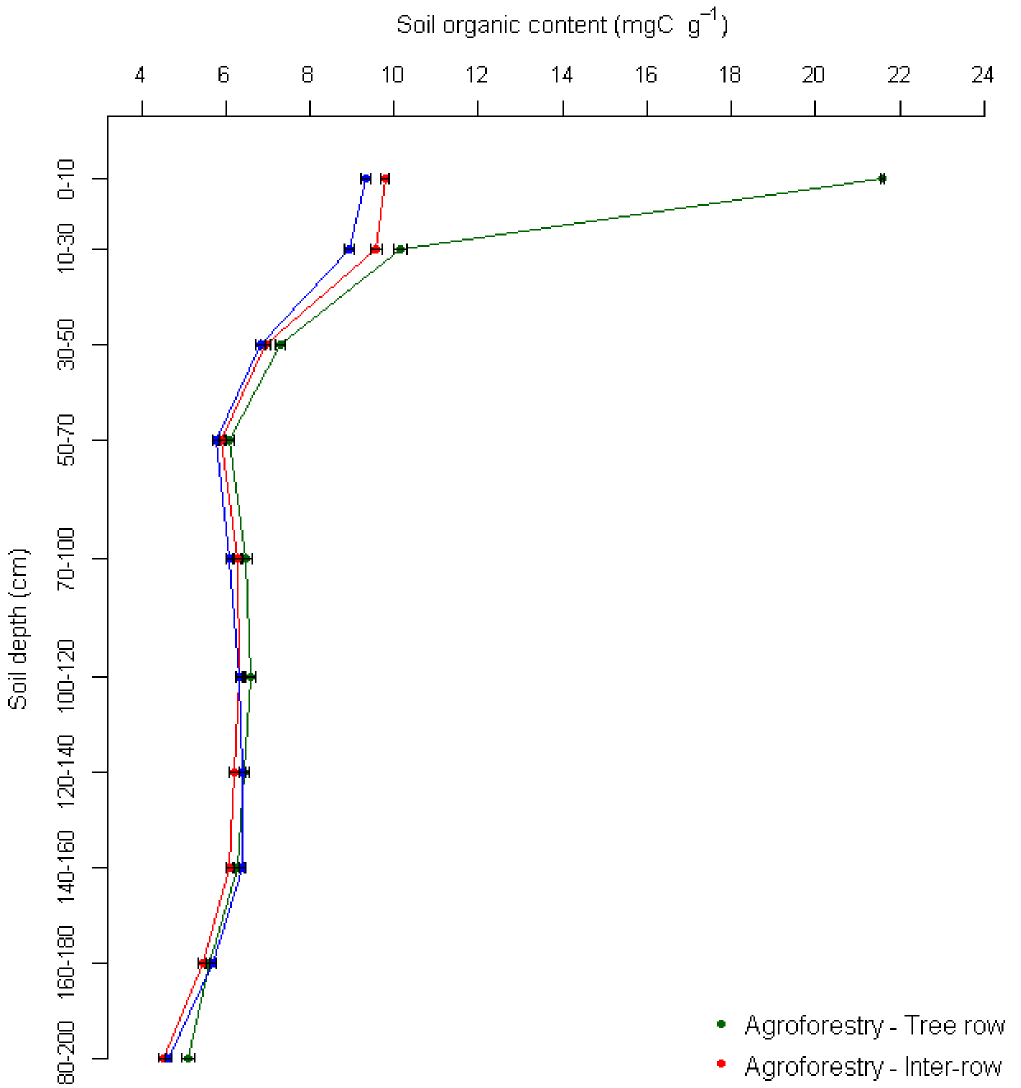


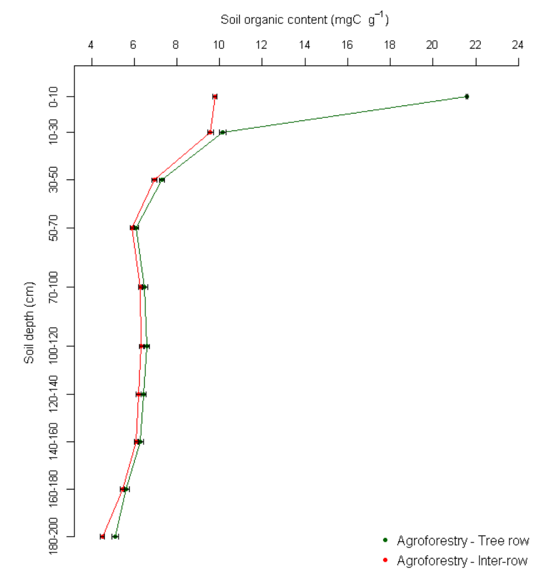
Error bars = Standard Error

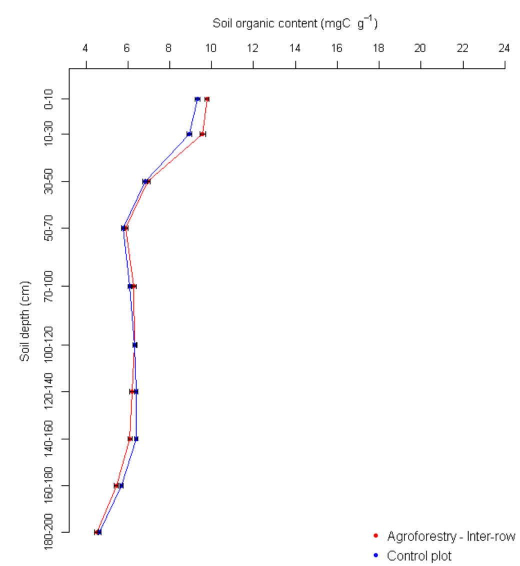
➔ On the surface $BD_{row} < BD_{ir} < BD_{c}$

➔ BD is higher in the control plot up to 1m20

➢ Results: 1. Quantify the SOC stocks – SOC contents







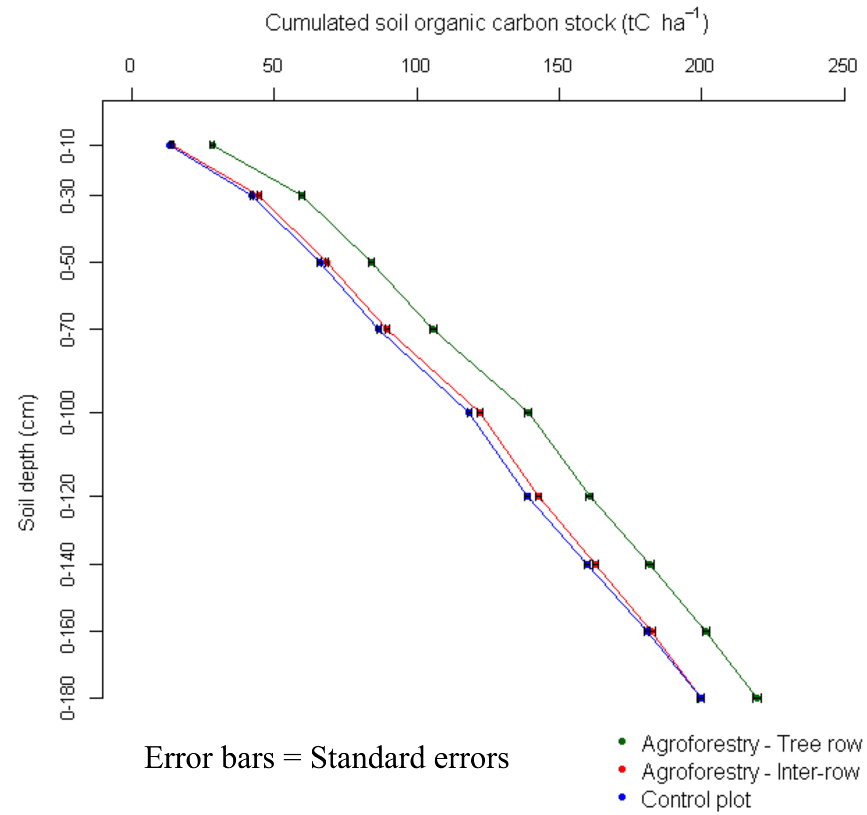
➔ SOC on the tree row > SOC on the inter-row up to 50cm depth

➔ SOC on the inter-row > SOC in the control plot up to 30cm depth

➔ From 1m20-1m40 to 1m60-1m80, SOC in the control plot > SOC on the inter-row…

➢ Results: 1. Quantify the SOC stocks – cumulated SOC stocks

Depth (cm)	Control (tC ha^{-1})	Inter-row (tC ha^{-1})	Tree row (tC ha^{-1})
0-10	13.34 ± 0.25	14.48 ± 0.30	28.27 ± 0.69
0-30	42.29 ± 0.53	44.79 ± 0.60	59.87 ± 0.92
0-50	65.83 ± 0.67	68.49 ± 0.71	84.12 ± 1.00
0-70	86.69 ± 0.75	89.58 ± 0.79	105.83 ± 1.07
0-100	118.48 ± 0.88	122.06 ± 0.94	139.25 ± 1.21
0-120	138.76 ± 0.92	142.51 ± 0.99	160.56 ± 1.25
0-140	159.79 ± 0.97	162.92 ± 1.03	181.72 ± 1.30
0-160	180.80 ± 1.02	182.51 ± 1.08	201.48 ± 1.34
0-180	199.66 ± 1.06	199.87 ± 1.12	219.49 ± 1.38



➔ The SOC stock in the **reference agriculture** plot was about **42.3 ± 0.5 MgC ha^{-1}** (0-30cm) and **118.5 ± 0.9 MgC ha^{-1}** (0-100cm)

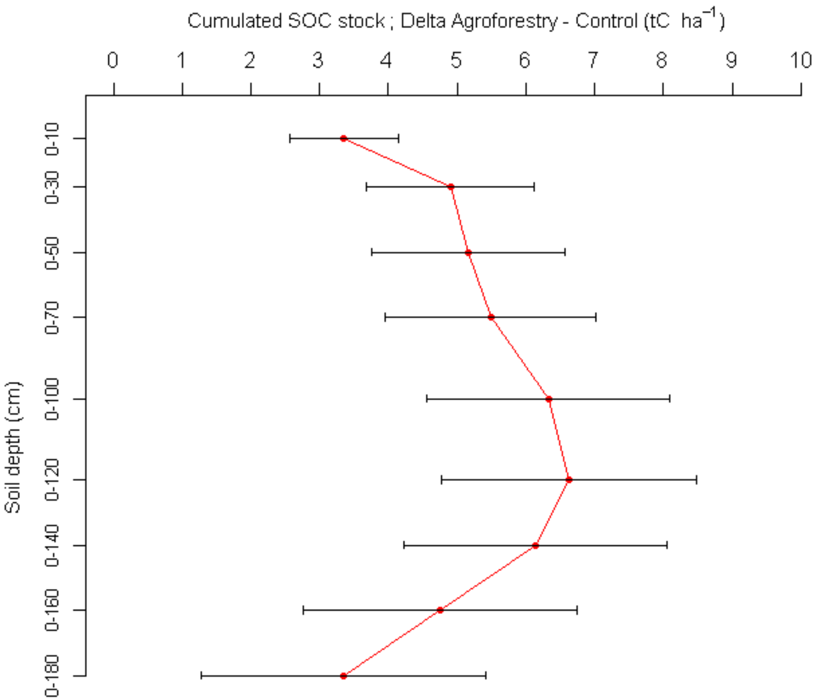
➔ In the **inter-row**, significant additional storage of **2.5 ± 0.8** and **3.5 ± 1.3 MgC ha^{-1}** was observed at 0-30 and 0-100cm respectively

➔ On the tree row, additional storage was **17.5 ± 1.1 and 20.5 ±1.5 MgC ha^{-1} respectively**

➢ Results: 1. Quantify the SOC stocks – cumulated SOC stocks

- Tree rows = 16% of the agroforestry plot
- Inter-rows = 84% of the agroforestry plot
- Age of the planting = 18 year old

Depth (cm)	Agroforestry (tC ha^{-1})	Control (tC ha^{-1})	Agroforestry-Control (tC ha^{-1})	Annual additionnal SOC storage rate (kgC ha^{-1} yr^{-1})
0-10	16.69 ± 0.75	13.34 ± 0.25	3.35 ± 0.79	186 ± 44
0-30	47.20 ± 1.10	42.29 ± 0.53	4.90 ± 1.22	272 ± 68
0-50	70.99 ± 1.23	65.83 ± 0.67	5.16 ± 1.40	287 ± 78
0-70	92.18 ± 1.33	86.69 ± 0.75	5.49 ± 1.53	305 ± 85
0-100	124.81 ± 1.53	118.48 ± 0.88	6.33 ± 1.77	352 ± 98
0-120	145.40 ± 1.60	138.76 ± 0.92	6.63 ± 1.85	368 ± 103
0-140	165.93 ± 1.66	159.79 ± 0.97	6.14 ± 1.92	341 ± 107
0-160	185.55 ± 1.72	180.80 ± 1.02	4.75 ± 2.00	264 ± 111
0-180	203.01 ± 1.78	199.66 ± 1.06	3.35 ± 2.07	186 ± 115



Error bars = Standard errors

➔ Annual additional SOC storage rates were estimated at **272 ± 68 kgC ha^{-1} yr^{-1}** (0-30cm) and **352 ± 68 kgC ha^{-1} yr^{-1}** (0-100cm)

➔ Without the tree rows (only inter-rows), these annual additional SOC storage rates would be **138 ± 45 kgC ha^{-1} yr^{-1}** (0-30cm) and **199 ± 72 kgC ha^{-1} yr^{-1}** (0-100cm)

➢ Results: 1. Quantify the SOC stocks – biomass C stock

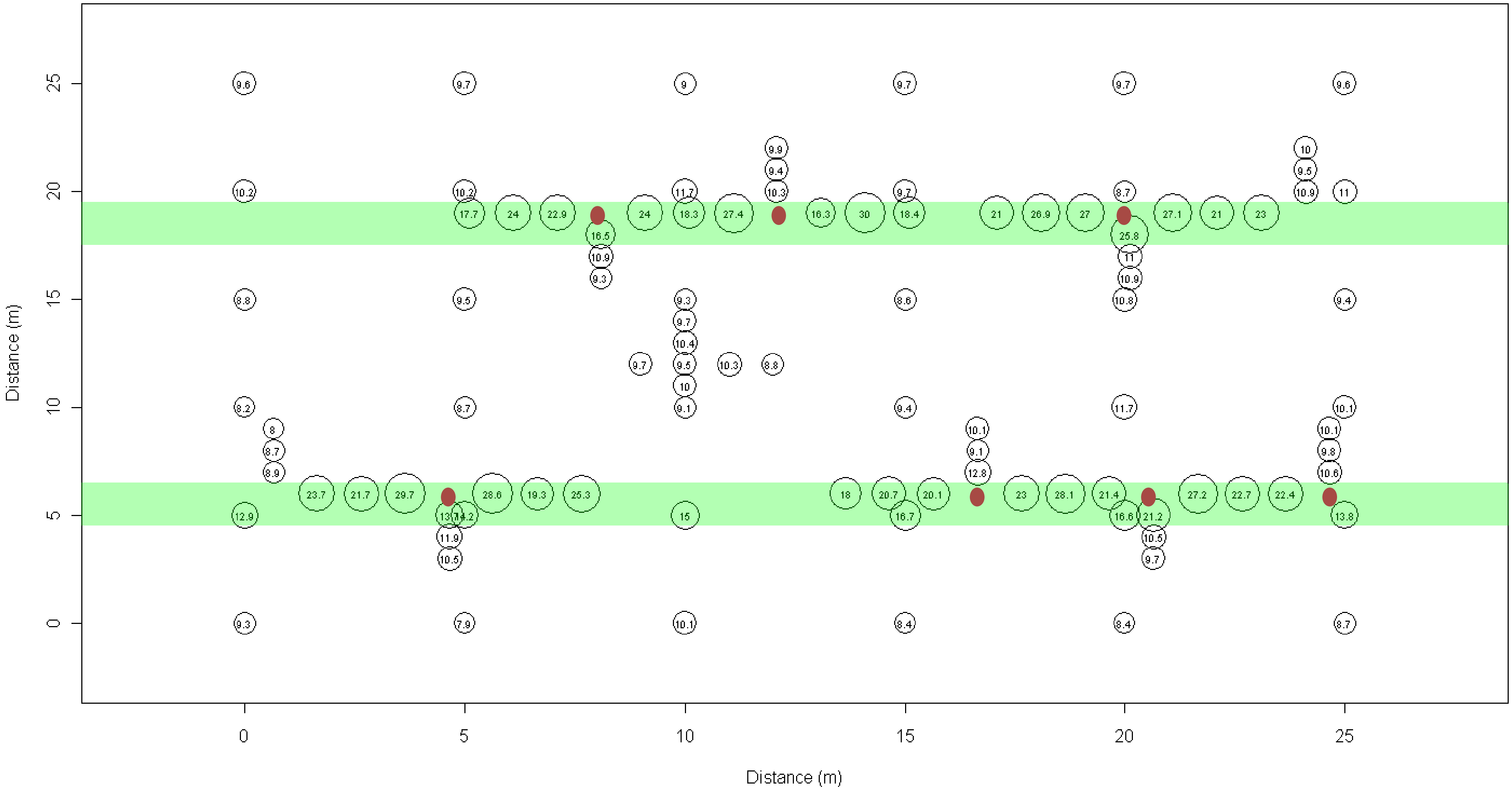
- We also estimated the aboveground biomass of 3 hybrid walnuts that were chopped down in 2012: about **140 kgC/tree** (65 trunk, 48 branches, 24 stump)

110 trees ha^{-1} = 15400 kgC ha^{-1} = 850 kgC ha^{-1} yr^{-1}
+ 350 kgC ha^{-1} yr^{-1} (soil C storage at 1m depth)
= **1.2 tC ha^{-1} yr^{-1}**

➔ Agroforestry systems have great potential to enhance C sequestration compared with tree-less agronomic systems (Mosquera-Losada, 2011)

Mosquera-Losada MR, Freese D, Rigueiro-Rodríguez A (2011). Carbon sequestration in European agroforestry systems. In: Kumar BM, Nair PKR (eds) Carbon sequestration potential of agroforestry systems. Springer, Netherlands, pp 43–59

➢ Results: 2. Spatial distribution of SOC stocks

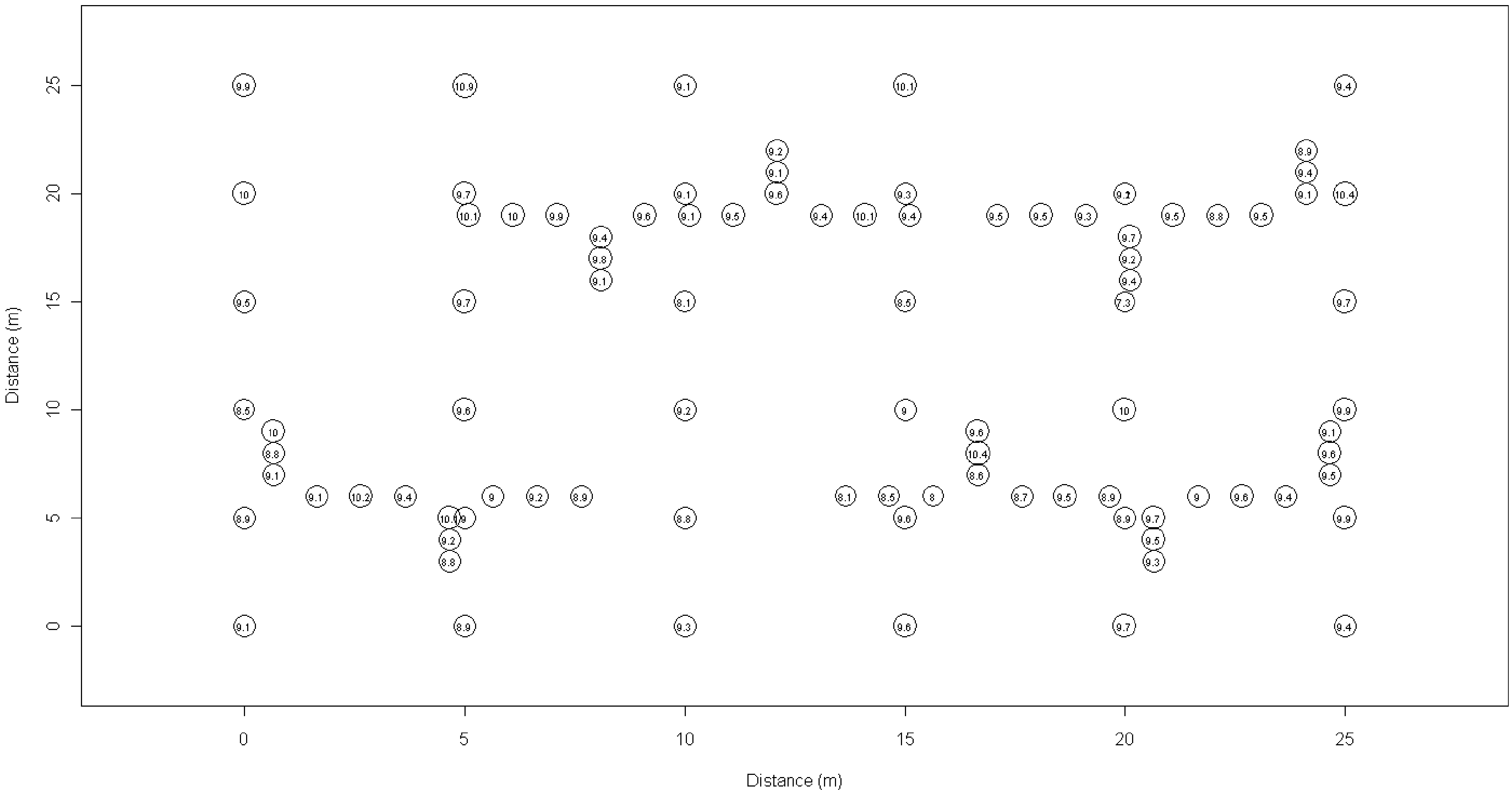


Soil organic carbon content (mgC g^{-1}) in the agroforestry plot down to 10cm depth

Hybrid walnut **Tree row**

➔ High spatial variability

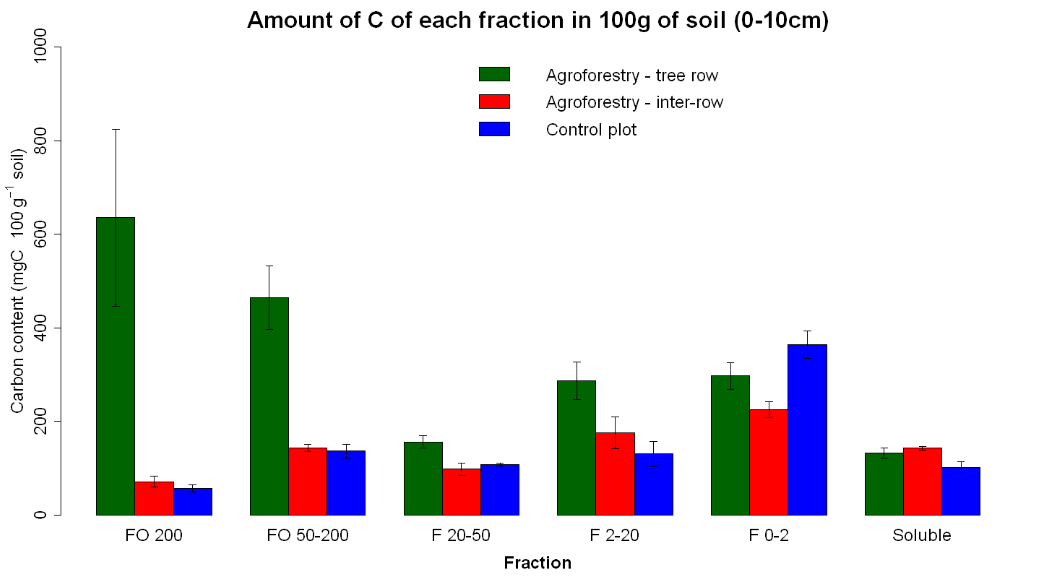
➢ Results: 2. Spatial distribution of SOC stocks

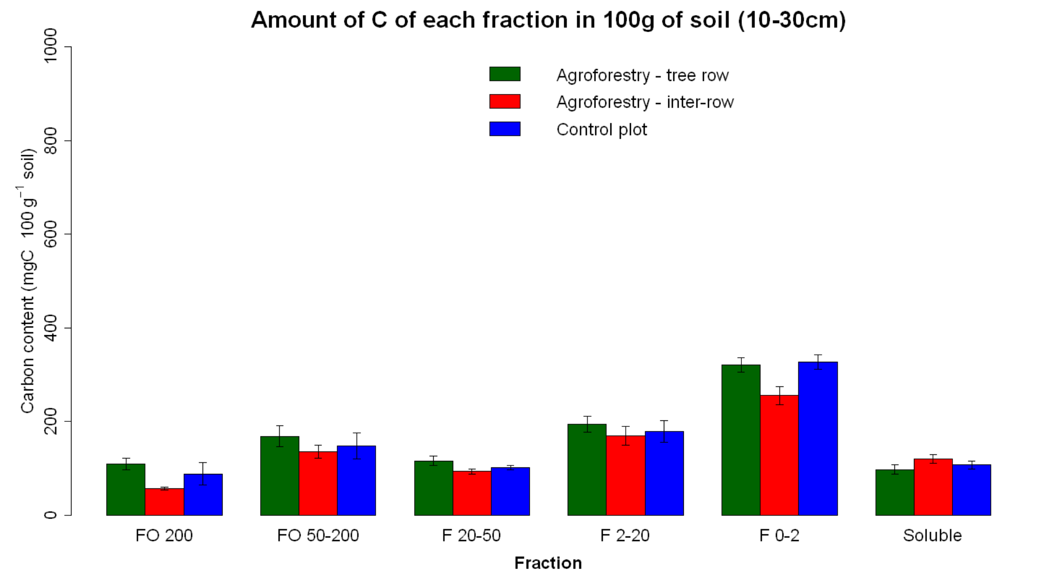


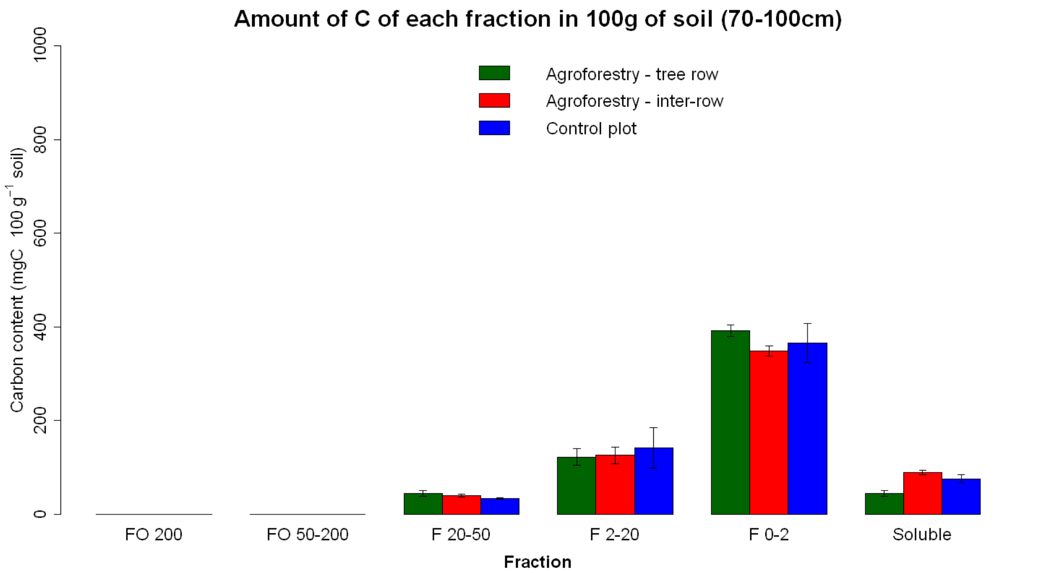
Soil organic carbon content (mgC g^{-1}) in the control plot down to 10cm depth

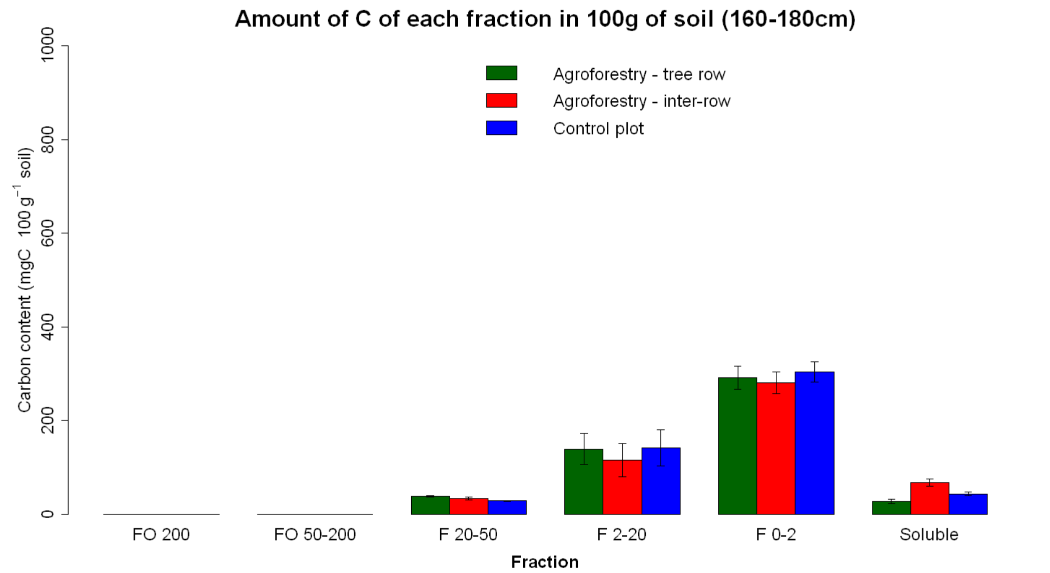
➔ No spatial variability

➢ Results: 3. Form of the additional C storage









Error bars = Standard errors

➢ Results: 3. Form of the additional C storage

	Delta Tree row agroforestry – Control (mgC g^{-1} soil)					
Depth (cm)	Bulk soil	Organic fraction >200µm	Organic fraction 50-200µm	Fraction 20-50µm	Fraction 2-20µm	Fraction 0-2µm
0-10	11.08	5.79 (52%)	3.28 (30%)	0.48 (4%)	1.56 (14%)	-
10-30	1.34	0.21 (15%)	0.32 (24%)	0.15 (11%)	0.15 (12%)	-

	Delta Tree row agroforestry – Inter-row agroforestry (mgC g^{-1} soil)					
Depth (cm)	Bulk soil	Organic fraction >200µm	Organic fraction 50-200µm	Fraction 20-50µm	Fraction 2-20µm	Fraction 0-2µm
0-10	10.48	5.64 (54%)	3.22 (31%)	0.58 (6%)	1.11 (11%)	0.72 (7%)
10-30	1.85	0.52 (28%)	0.33 (18%)	0.23 (12%)	0.25 (13%)	0.65 (35%)

➔ **0-10cm:** 80-85% of the additional C storage on the tree row is explained by labile organic fractions. About 15% to 20% of this additional C storage is localized in fine particles

➔ **10-30cm:** 40-50% of the additional C storage on the tree row is explained by labile organic fractions. About 50% of this additional C storage is localized in fine particles

Conclusion

- ➔ 18 years after the tree planting, we were able to observe an additional C storage into the soil

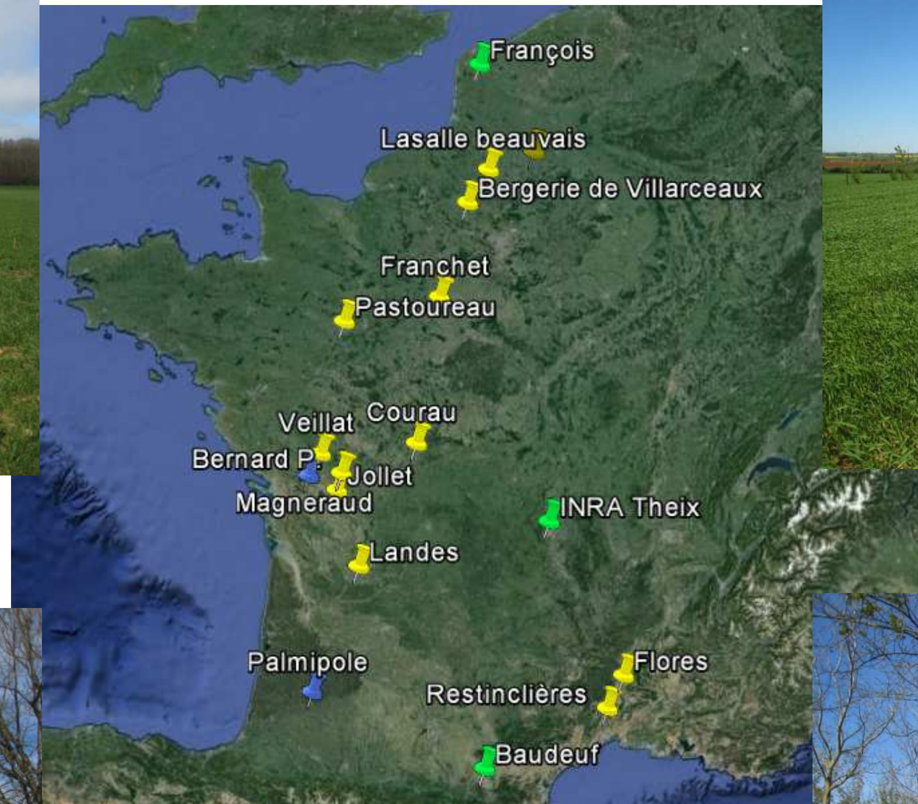
- ➔ Additional SOC storage rates are higher than those of other techniques like no-till farming or conservation agriculture. Combine both?

- ➔ The SOC storage is very spatially influenced, importance of tree rows

- ➔ SOC storage mainly concern shallow soil horizons, and most of additional C is not stablized on mineral particles. A pertubation of the system would release this C

➢ A network of agroforestry fields currently being sampled…

2008



2008

1975

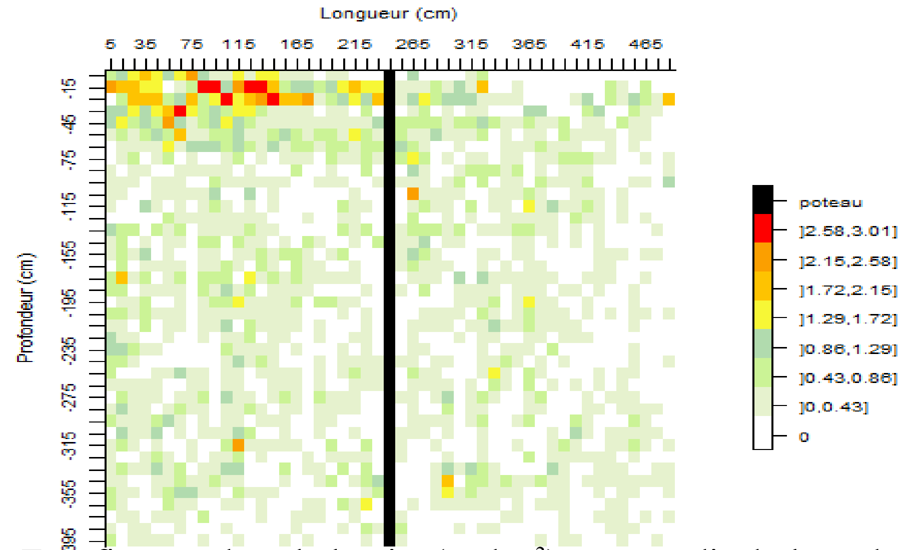
1989

1995

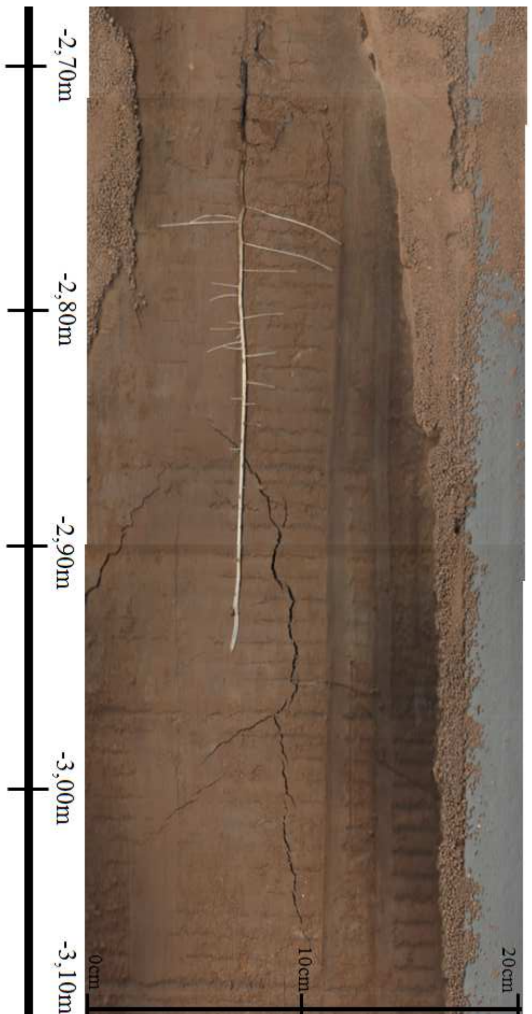
➔ 807 soil cylinders have been sampled

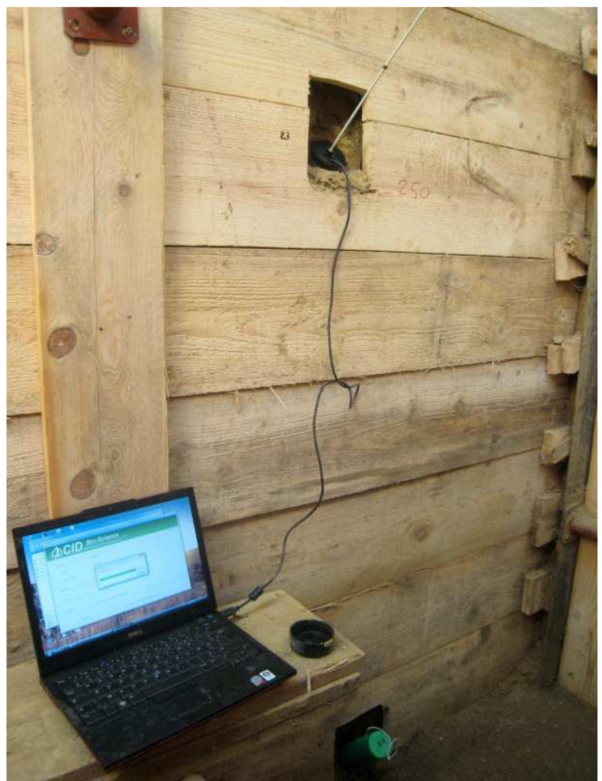
➢ Estimation of the C inputs in an agroforestry system

Tree fine root mapping



Tree fine root length density (m dm^{-3}) – perpendicularly to the tree row



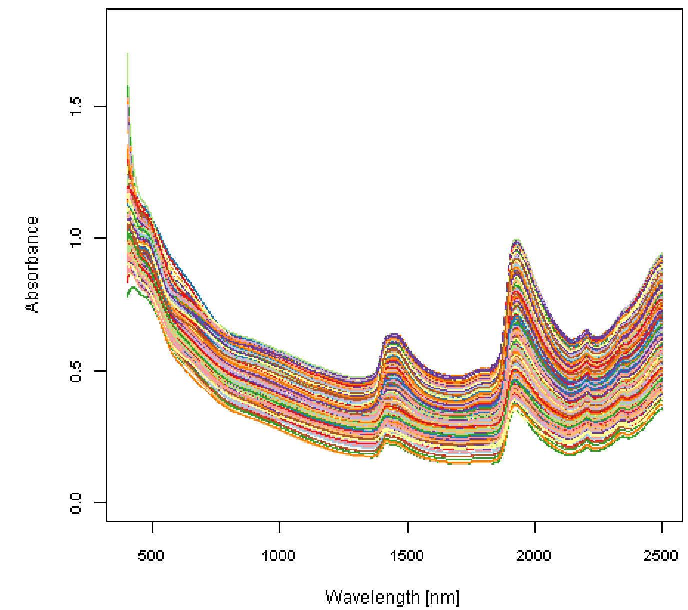


Minirhizotron

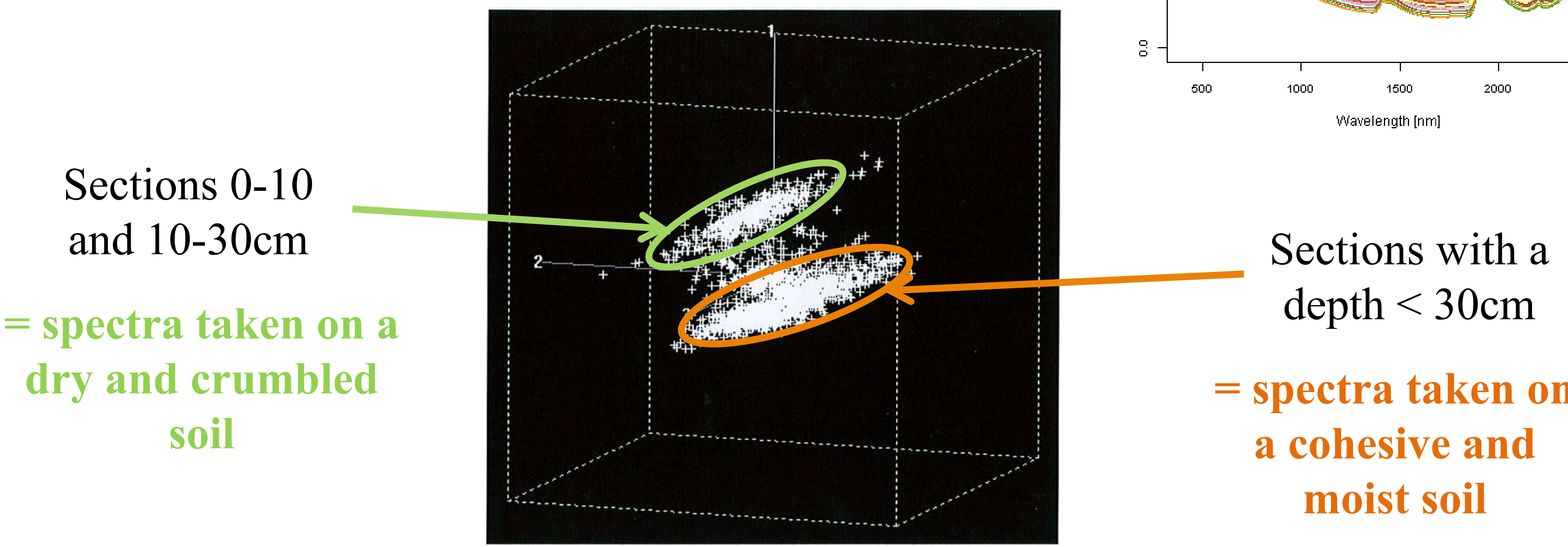
Any question?

➤ Material and Methods: spectroscopy models

- 1908 mean spectra = 1908 soil organic contents and 1908 bulk densities



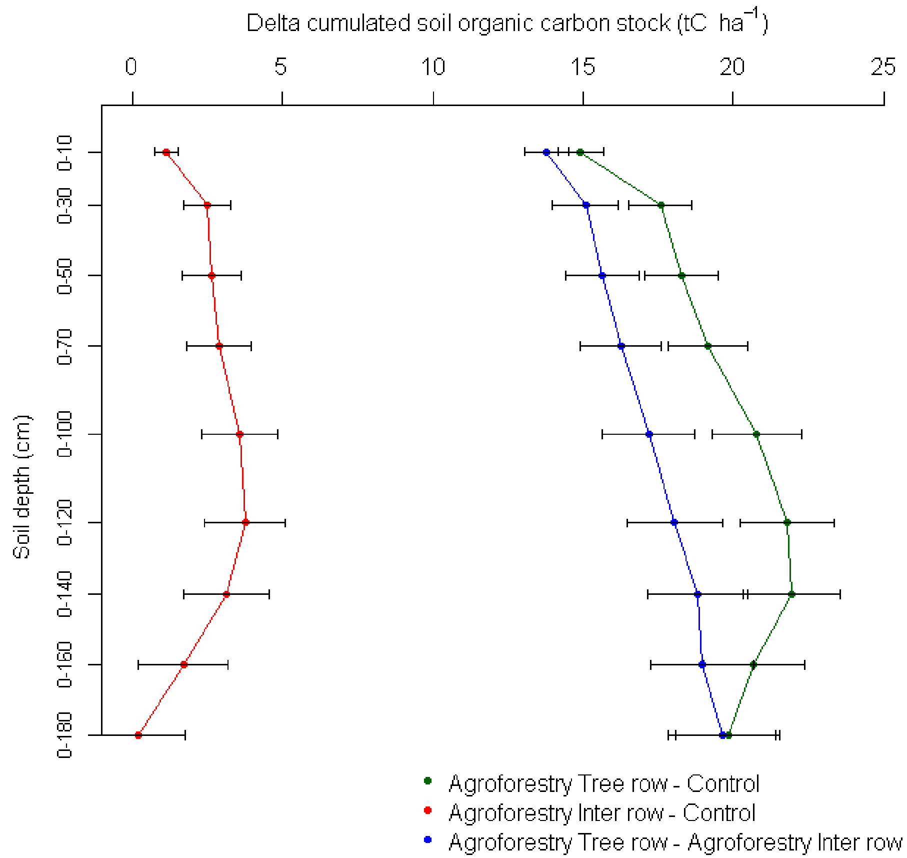
- With a PCA, we observed 2 populations of spectra…



… the result of a different soil structure and soil moisture

- We need two different predictive models

➢ Results: 1. Quantify the SOC stocks – discussion

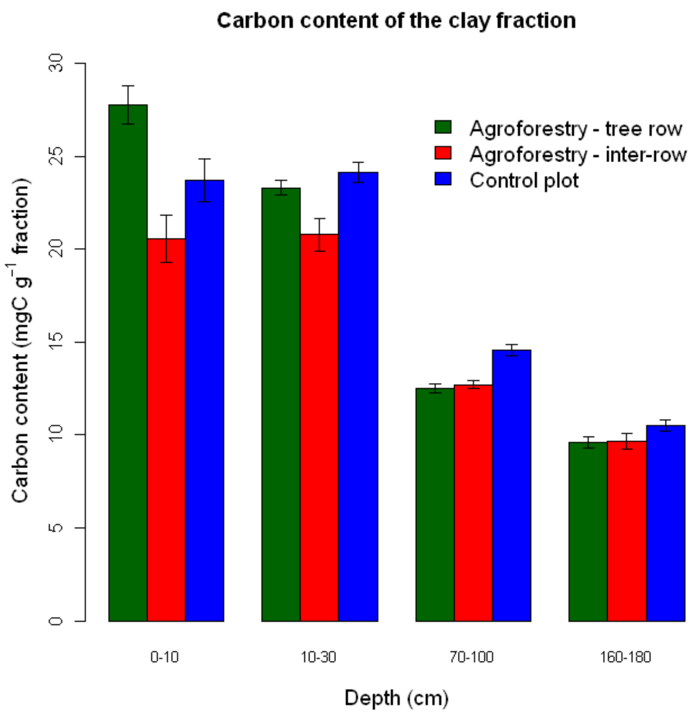


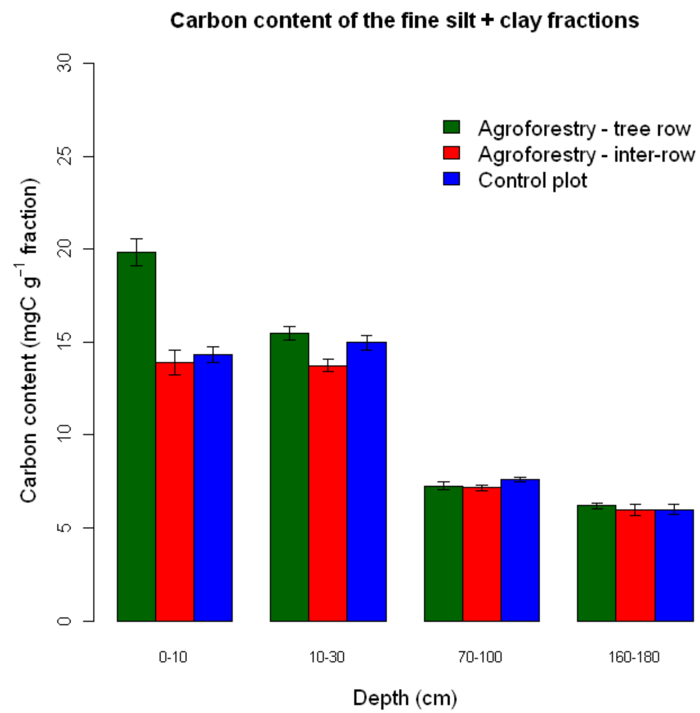
- Two hypotheses to explain the shift around 1m20:

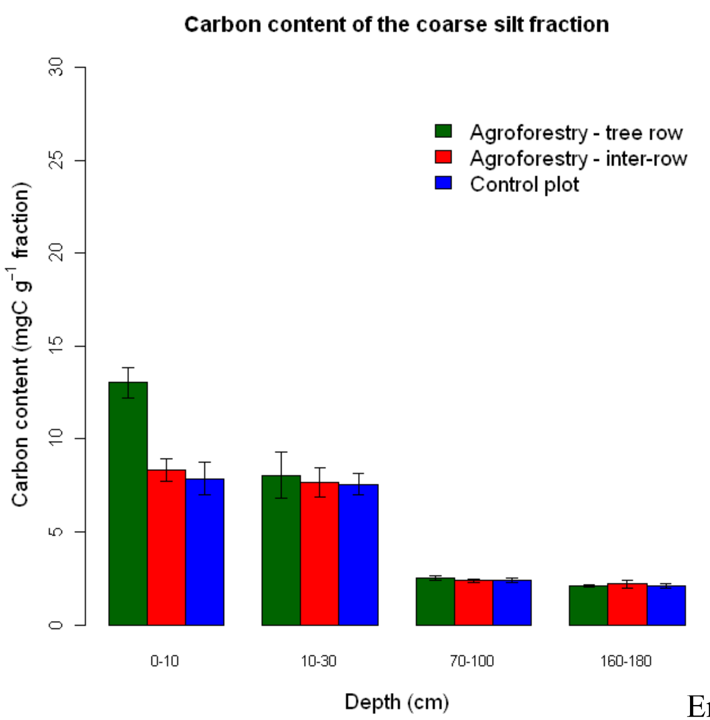
➔initial difference in soil texture between the control and the agroforestry plot under 1m20 (different types of clay, higher C content of clay particles, hydrology…)

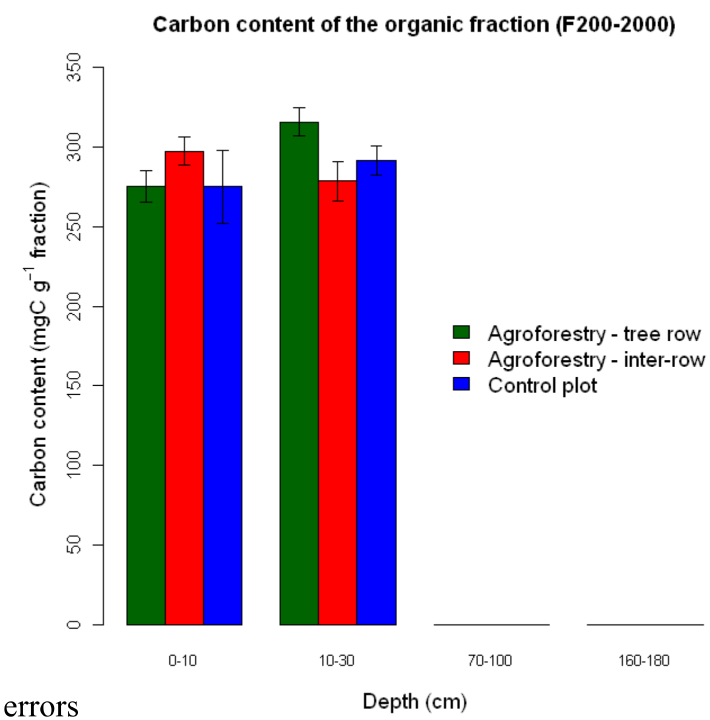
➔priming effect due to the trees ?

➢ Results: 3. Form of the additional C storage

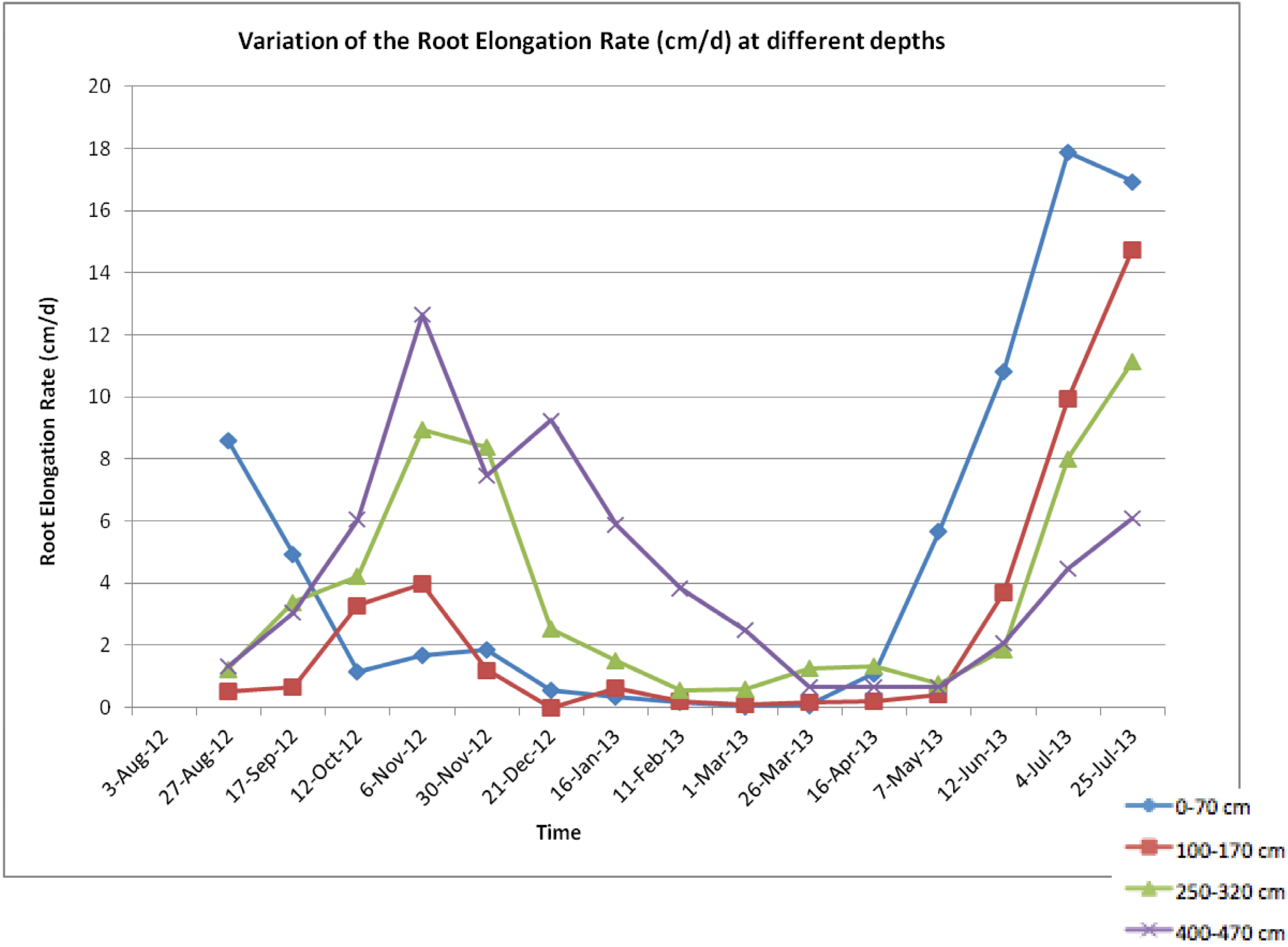


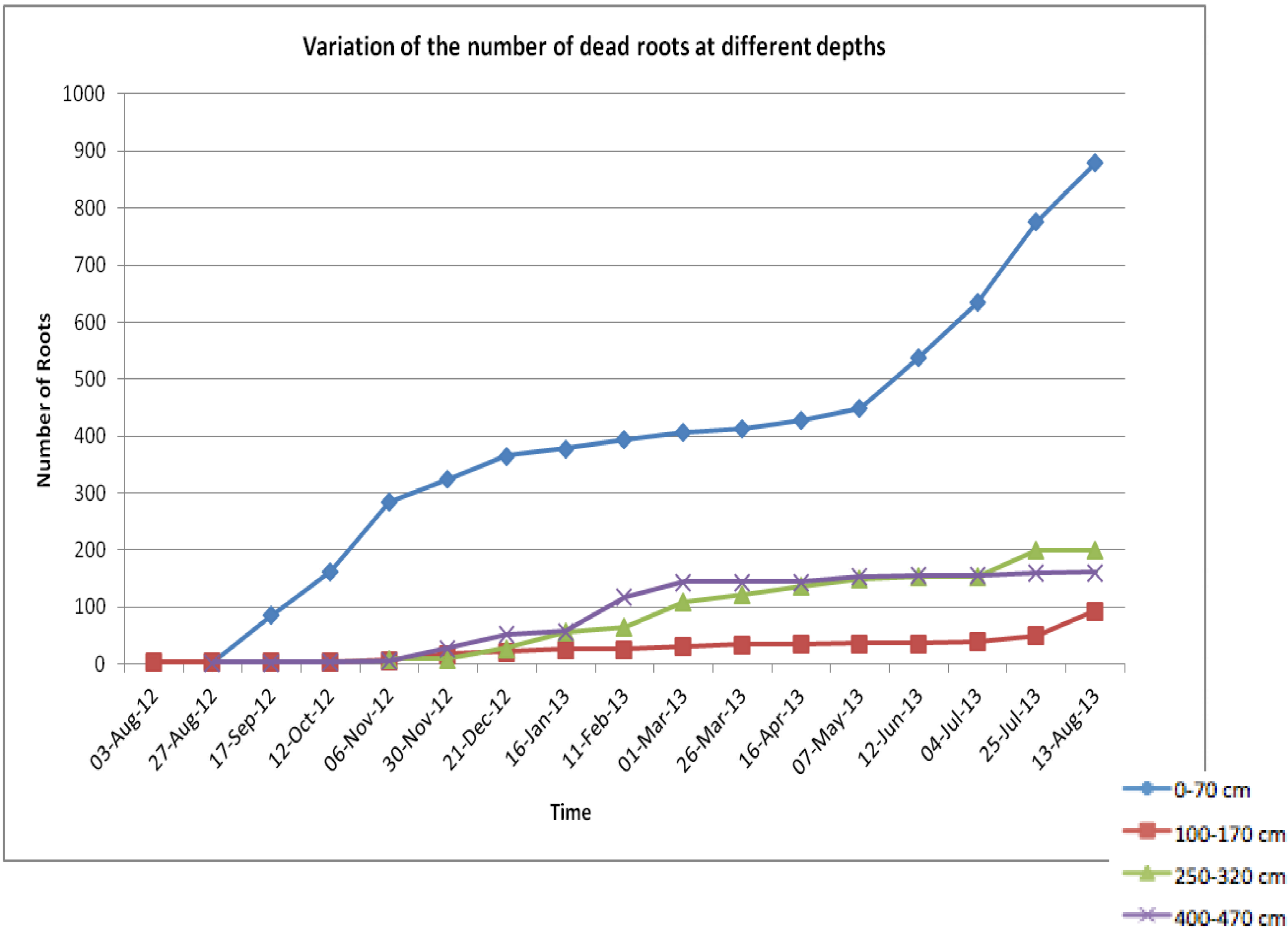


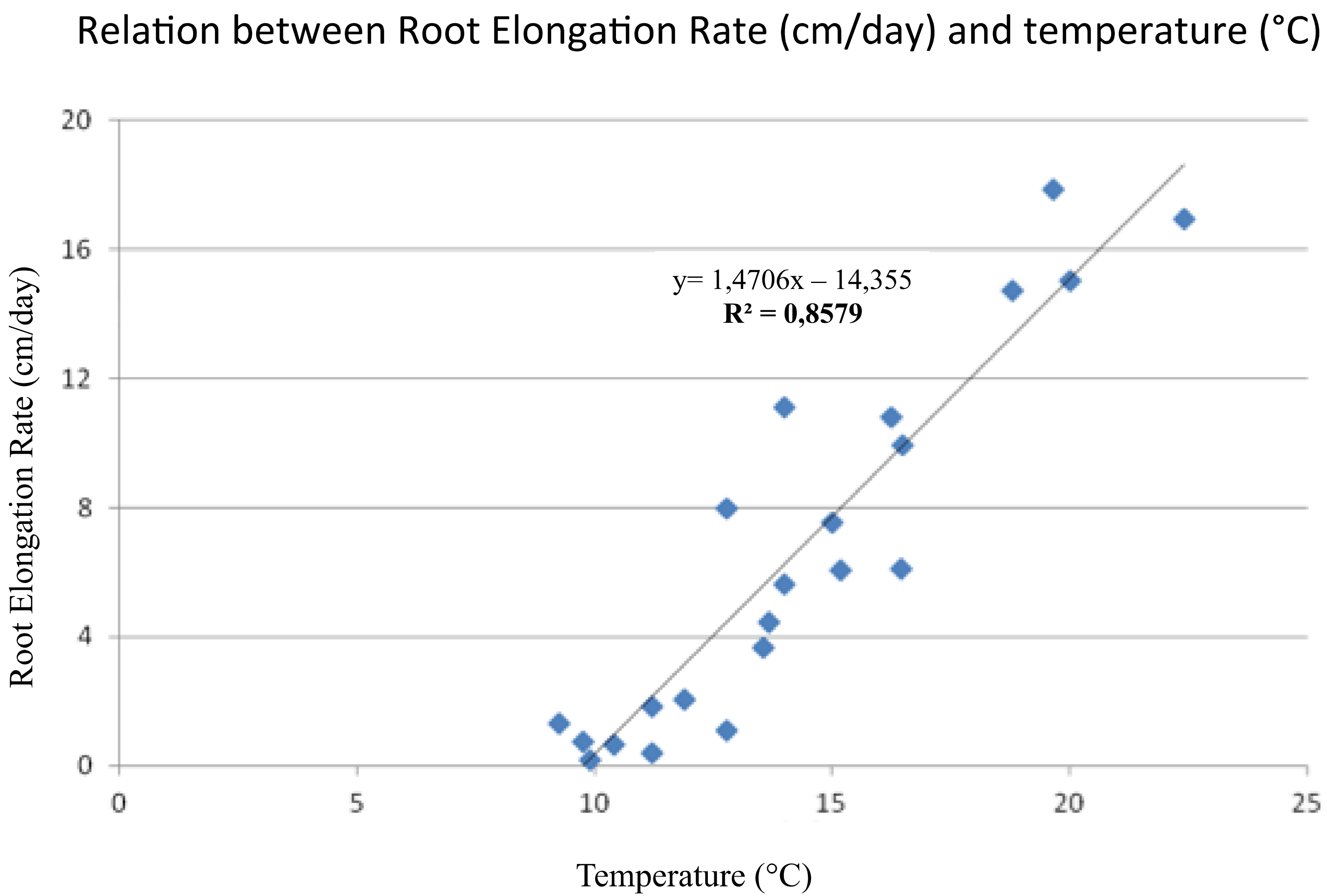




Error bars = Standard errors


Variation of the Root Elongation Rate (cm/d) at different depths
Root Elongation Rate (cm/d)
20
18
16
14
12
10
8
6
4
2
0
3-Aug-12
27-Aug-12
17-Sep-12
12-Oct-12
6-Nov-12
30-Nov-12
21-Dec-12
16-Jan-13
11-Feb-13
1-Mar-13
26-Mar-13
16-Apr-13
7-May-13
12-Jun-13
4-Jul-13
25-Jul-13
Time
0-70 cm
100-170 cm
250-320 cm
400-470 cm


Variation of the number of dead roots at different depths
Number of Roots
1000
900
800
700
600
500
400
300
200
100
0
03-Aug-12
27-Aug-12
17-Sep-12
12-Oct-12
06-Nov-12
30-Nov-12
21-Dec-12
16-Jan-13
11-Feb-13
01-Mar-13
26-Mar-13
16-Apr-13
07-May-13
12-Jun-13
04-Jul-13
25-Jul-13
13-Aug-13
Time
0-70 cm
100-170 cm
250-320 cm
400-470 cm


Relation between Root Elongation Rate (cm/day) and temperature (°C)
y= 1,4706x – 14,355
R² = 0,8579
Root Elongation Rate (cm/day)
Temperature (°C)
0
4
8
12
16
20
0
5
10
15
20
25