The CO2-induced acceleration of soil organic carbon mineralization counteracted by legumes

Camille Cros, Gaël Alvarez, Sébastien Fontaine

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CROS Camille, ALVAREZ Gaël,

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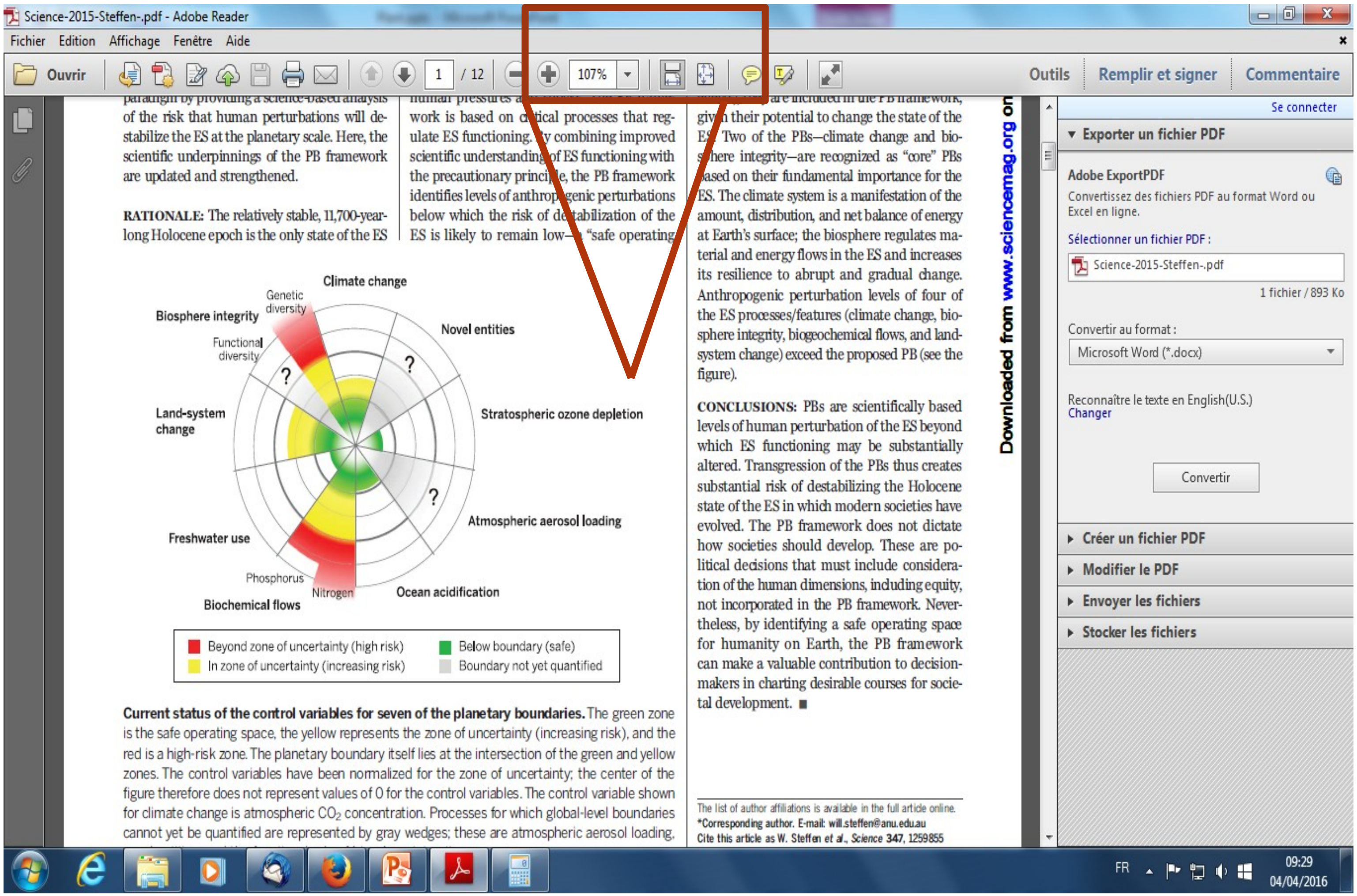
Impacts of human activities



of the risk that human perturbations will destabilize the ES at the planetary scale. Here, the scientific underpinnings of the PB framework are updated and strengthened.

RATIONALE: The relatively stable, 11,700-year-long Holocene epoch is the only state of the ES ... work is based on critical processes that regulate ES functioning. By combining improved scientific understanding of ES functioning with the precautionary principle, the PB framework identifies levels of anthropogenic perturbations below which the risk of destabilization of the ES is likely to remain low—a "safe operating ...

Current status of the control variables for seven of the planetary boundaries. The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), and the red is a high-risk zone. The planetary boundary itself lies at the intersection of the green and yellow zones. The control variables have been normalized for the zone of uncertainty; the center of the figure therefore does not represent values of 0 for the control variables. The control variable shown for climate change is atmospheric CO_2 concentration. Processes for which global-level boundaries cannot yet be quantified are represented by gray wedges; these are atmospheric aerosol loading, ...

... given their potential to change the state of the ES. Two of the PBs—climate change and biosphere integrity—are recognized as "core" PBs based on their fundamental importance for the ES. The climate system is a manifestation of the amount, distribution, and net balance of energy at Earth's surface; the biosphere regulates material and energy flows in the ES and increases its resilience to abrupt and gradual change. Anthropogenic perturbation levels of four of the ES processes/features (climate change, biosphere integrity, biogeochemical flows, and land-system change) exceed the proposed PB (see the figure).

CONCLUSIONS: PBs are scientifically based levels of human perturbation of the ES beyond which ES functioning may be substantially altered. Transgression of the PBs thus creates substantial risk of destabilizing the Holocene state of the ES in which modern societies have evolved. The PB framework does not dictate how societies should develop. These are political decisions that must include consideration of the human dimensions, including equity, not incorporated in the PB framework. Nevertheless, by identifying a safe operating space for humanity on Earth, the PB framework can make a valuable contribution to decision-makers in charting desirable courses for societal development. ■

The list of author affiliations is available in the full article online.
*Corresponding author. E-mail: will.steffen@anu.edu.au
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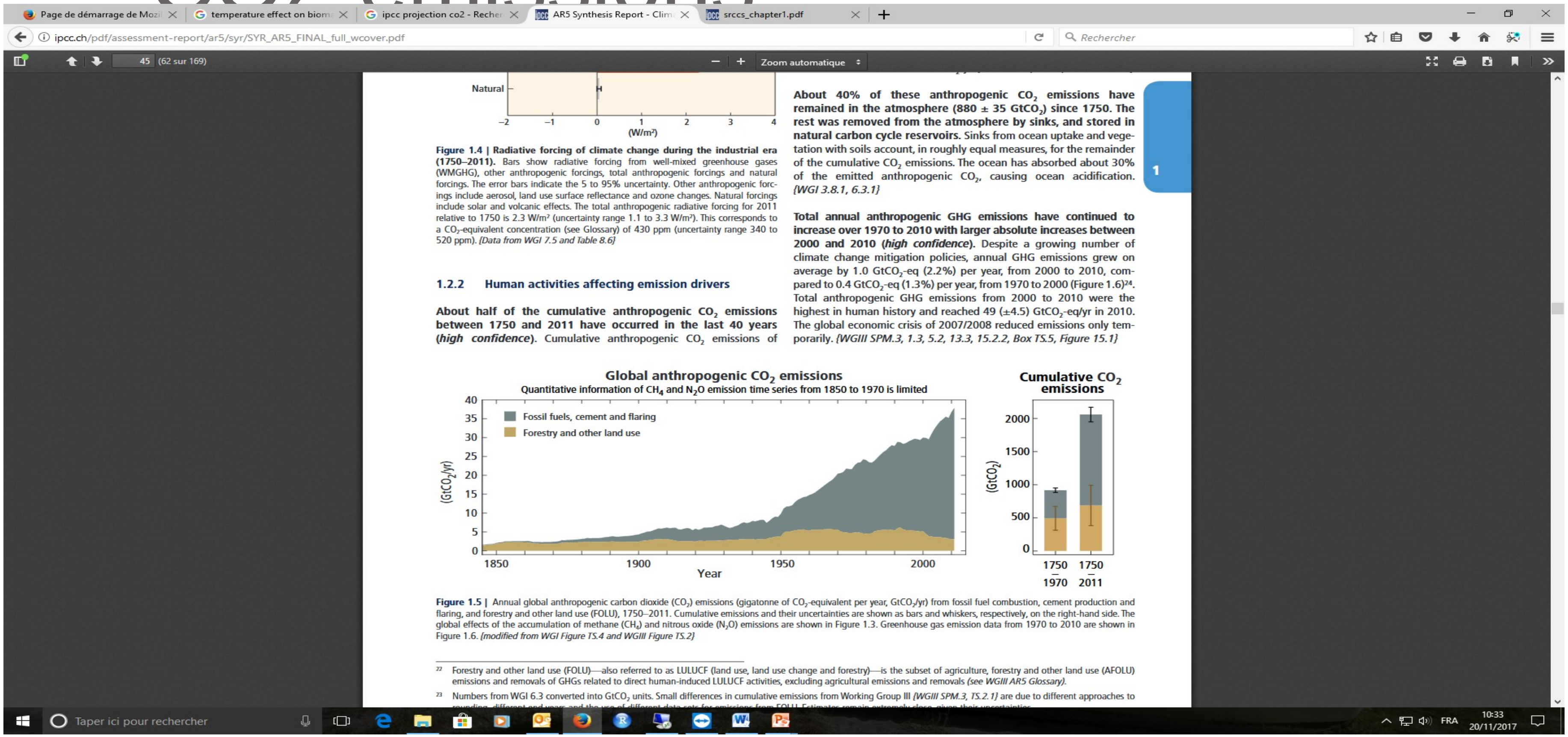
Steffen *et al.*, 2015

Impacts of human activities on CO2 emissions



Natural

−2 −1 0 1 2 3 4
(W/m²)

Figure 1.4 | Radiative forcing of climate change during the industrial era (1750–2011). Bars show radiative forcing from well-mixed greenhouse gases (WMGHG), other anthropogenic forcings, total anthropogenic forcings and natural forcings. The error bars indicate the 5 to 95% uncertainty. Other anthropogenic forcings include aerosol, land use surface reflectance and ozone changes. Natural forcings include solar and volcanic effects. The total anthropogenic radiative forcing for 2011 relative to 1750 is 2.3 W/m² (uncertainty range 1.1 to 3.3 W/m²). This corresponds to a CO_2-equivalent concentration (see Glossary) of 430 ppm (uncertainty range 340 to 520 ppm). *{Data from WGI 7.5 and Table 8.6}*

1.2.2 Human activities affecting emission drivers

About half of the cumulative anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*). Cumulative anthropogenic CO_2 emissions of

About 40% of these anthropogenic CO_2 emissions have remained in the atmosphere (880 ± 35 $GtCO_2$) since 1750. The rest was removed from the atmosphere by sinks, and stored in natural carbon cycle reservoirs. Sinks from ocean uptake and vegetation with soils account, in roughly equal measures, for the remainder of the cumulative CO_2 emissions. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. *{WGI 3.8.1, 6.3.1}*

Total annual anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010 (*high confidence*). Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 $GtCO_2$-eq (2.2%) per year, from 2000 to 2010, compared to 0.4 $GtCO_2$-eq (1.3%) per year, from 1970 to 2000 (Figure 1.6)[24]. Total anthropogenic GHG emissions from 2000 to 2010 were the highest in human history and reached 49 (±4.5) $GtCO_2$-eq/yr in 2010. The global economic crisis of 2007/2008 reduced emissions only temporarily. *{WGIII SPM.3, 1.3, 5.2, 13.3, 15.2.2, Box TS.5, Figure 15.1}*

Figure 1.5 | Annual global anthropogenic carbon dioxide (CO_2) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$/yr) from fossil fuel combustion, cement production and flaring, and forestry and other land use (FOLU), 1750–2011. Cumulative emissions and their uncertainties are shown as bars and whiskers, respectively, on the right-hand side. The global effects of the accumulation of methane (CH_4) and nitrous oxide (N_2O) emissions are shown in Figure 1.3. Greenhouse gas emission data from 1970 to 2010 are shown in Figure 1.6. *{modified from WGI Figure TS.4 and WGIII Figure TS.2}*

[22] Forestry and other land use (FOLU)—also referred to as LULUCF (land use, land use change and forestry)—is the subset of agriculture, forestry and other land use (AFOLU) emissions and removals of GHGs related to direct human-induced LULUCF activities, excluding agricultural emissions and removals *(see WGIII AR5 Glossary)*.

[23] Numbers from WGI 6.3 converted into $GtCO_2$ units. Small differences in cumulative emissions from Working Group III *{WGIII SPM.3, TS.2.1}* are due to different approaches to

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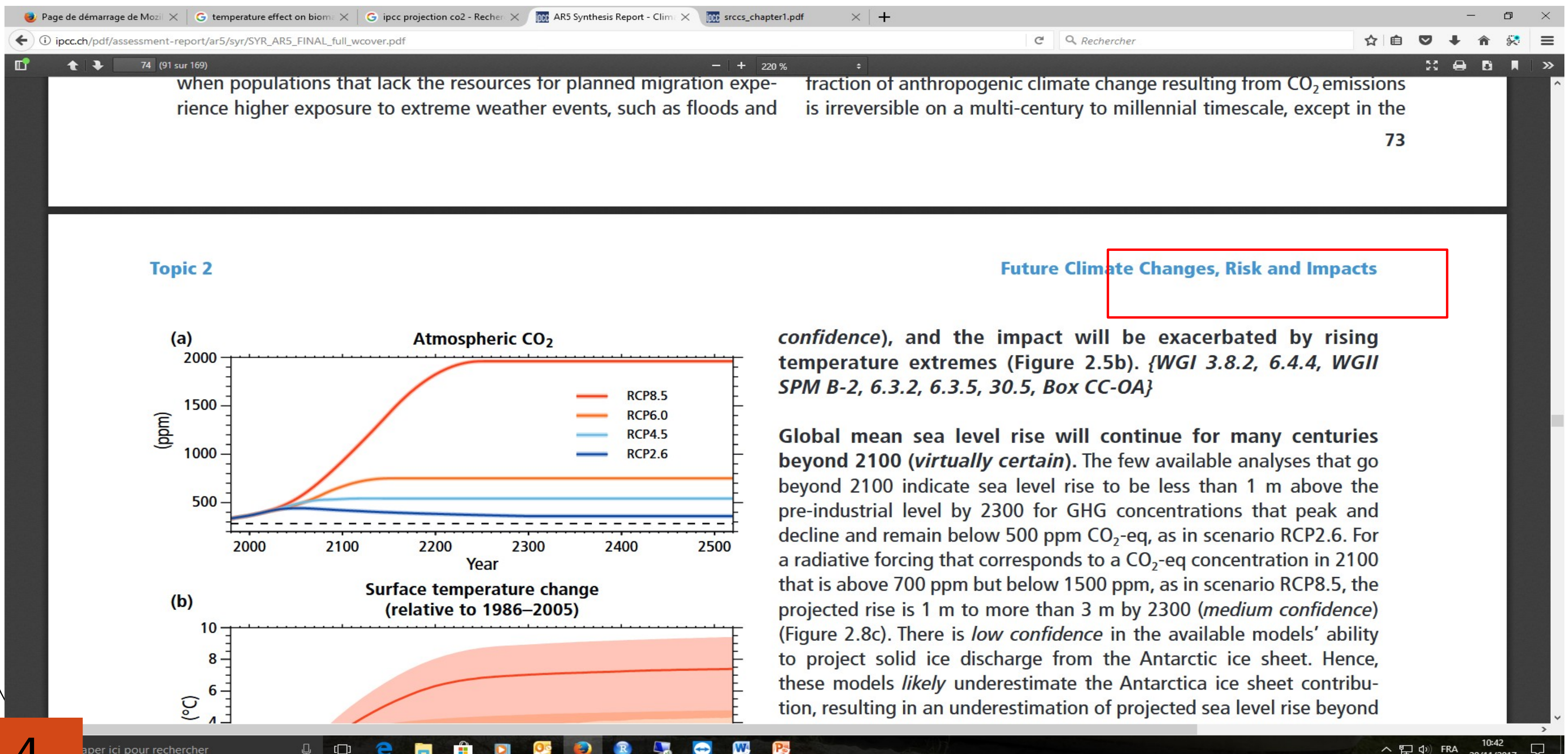
Consequences of human activities
climate change

IPPC projections:



when populations that lack the resources for planned migration experience higher exposure to extreme weather events, such as floods and

fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the

73

Topic 2

Future Climate Changes, Risk and Impacts

confidence), **and the impact will be exacerbated by rising temperature extremes (Figure 2.5b).** ***{WGI 3.8.2, 6.4.4, WGII SPM B-2, 6.3.2, 6.3.5, 30.5, Box CC-OA}***

Global mean sea level rise will continue for many centuries beyond 2100 (*virtually certain*). The few available analyses that go beyond 2100 indicate sea level rise to be less than 1 m above the pre-industrial level by 2300 for GHG concentrations that peak and decline and remain below 500 ppm CO_2-eq, as in scenario RCP2.6. For a radiative forcing that corresponds to a CO_2-eq concentration in 2100 that is above 700 ppm but below 1500 ppm, as in scenario RCP8.5, the projected rise is 1 m to more than 3 m by 2300 (*medium confidence*) (Figure 2.8c). There is *low confidence* in the available models' ability to project solid ice discharge from the Antarctic ice sheet. Hence, these models *likely* underestimate the Antarctica ice sheet contribution, resulting in an underestimation of projected sea level rise beyond

IPPC 2016 report

Effect of elevated CO2 on planted ecosystem

- Stimulation of growth primary production increase plant production

vated – 460 μmol mol^{-1}) in *Gmelina arborea* recorded at the end of two growth seasons (Rasineni and Reddy, unpublished data)

Character	Ambient CO_2	Elevated CO_2
Plant height (cm)	209.45 ± 2.12	359.92 ± 2.78***
Basal diameter (cm)	13.21 ± 0.59	28.40 ± 0.80***
Number of branches	26.20 ± 0.72	44.20 ± 1.19***
Total shoot length (m)	30.73 ± 1.05	59.62 ± 1.43**
Number of leaves/longest shoot	52.70 ± 2.00	108.60 ± 3.12***
Leaf length (cm)	28.10 ± 0.98	37.62 ± 1.12**
Relative plant height growth rate (g day^{-1})	2.97 ± 0.45	4.08 ± 0.72**
Leaf size expansion rate	3.89 ± 0.57	9.75 ± 1.02***
Root weight (kg)	3.96 ± 0.89	5.97 ± 0.85**
Leaf weight (kg)	10.81 ± 1.03	15.54 ± 2.12***
Stem weight (kg)	14.86 ± 0.75	22.13 ± 3.12***
Aerial biomass (kg)	25.67 ± 2.32	37.67 ± 2.98**
Plant biomass (kg)	29.63 ± 1.67	43.64 ± 3.12***

Values are mean ± SD. Values were tested by paired *t*-test, ***$p < 0.001$, **$p < 0.01$

Figure 1. Five-month-old *Gmelina arborea* plants grown in open top chambers under ambient (*a*) and elevated (*b*) CO_2 concentrations. CO_2 was supplied from a high pressure CO_2 cylinder, injected through pressure regulator and was monitored by a CO_2 analyser. The height of ambient CO_2 grown plant was ~ 210 cm, while that of the plant grown under elevated CO_2 was ~ 360 cm. The other growth characteristics of these plants are shown in Table 2. After screening several tree species for their growth characteristics under elevated CO_2, we have selected *G. arborea* as its growth was found to be very fast in response to increased CO_2 concentrations.

top chambers (4 × 4 × 4 m, Figure 1), demonstrated a

altered branching pattern and significant increase in plant height. We attribute the positive correlation between photosynthesis and the morphological characteristics of *Gmelina* to be due to potential sink capacity which is crucial to the understanding of the physiological, biochemical, genetic and environmental limitations for the productivity in plants grown in CO_2-enriched atmosphere. These potential changes in the growth and development of *Gmelina* under elevated CO_2 may also be ascribed to increased cell division, cell expansion, cell differentiation and organogenesis, stimulated by increased carbon and more efficient water use[69]. We believe that optimal utilization of resources and well-balanced source–sink activity might enhance carbon gain in plants grown under elevated CO_2. However, the ability of exploiting the extra carbon by any plant species might largely be a function of its inherent structural and physiological attributes, integrated with the plasticity of morphological and anatomical characteristics.

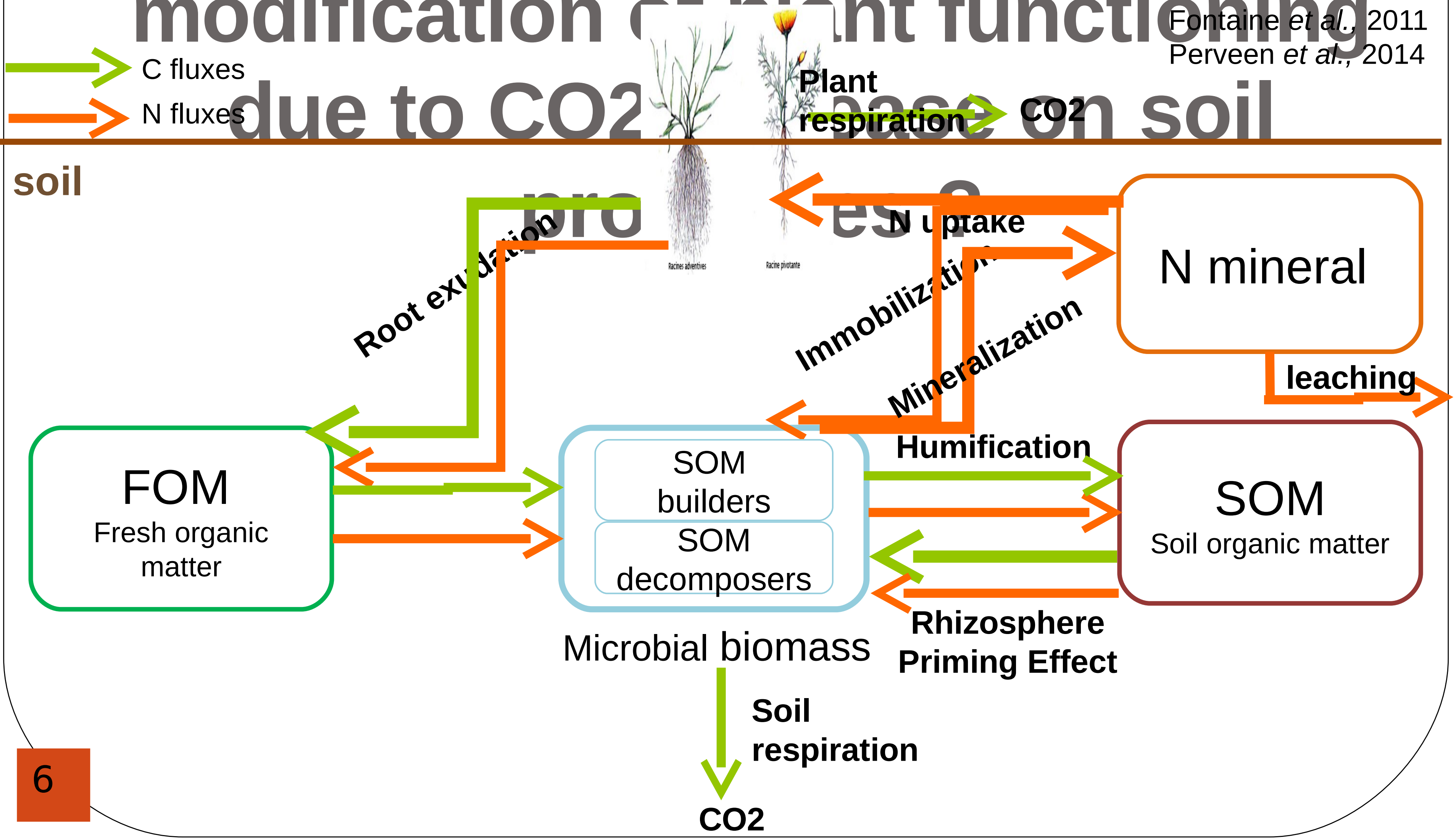
Other factors which can influence plant responses to elevated CO_2 are the growth environment, soil nutrition and the genetic organization of the plant species. The direct effects of rising CO_2 on plant growth and metabolism are a modulation of stomatal conductance, changes in carboxylation capacity, and accumulation of photoassimalates. These three regulatory mechanisms will have a wide range of indirect effects on growth and development of plants, as shown in Figure 2. Davey *et al.*[7] postu-

From Reddy *et al.*, 2010

Diaz *et al.*, 1993 ; Zanetti *et al.*, 1996; Cheng 1999; hu 2001; Schneider *et al.*, 2004; Groenigen *et al.*, 2006

What is the consequences of modification of plant functioning due to CO_2 […]ase on soil pro[…]es ?

Fontaine *et al.*, 2011
Perveen *et al.*, 2014



Hypothesis

What is the consequences of modification of plant functioning due to CO_2 increase on soil processes ?

CO_2 +

Photosynthesis stimulation

1. Biomass increasing (+ root exudation)
2. Decrease of mineral N
3. RPE increasing
4. Destocking SOM

Design

- 2 species
- Sown in September 2016
- CO2 levels (C ambiant: 400 ppm; C elevete ppm)
- 4 replicates
- 3 plants destructives harvests

Bare soil

English ryegrass

monocrop

Intercrop with white clover

Ambiant CO2

Eleveted CO2

Ambiant CO2

Eleveted CO2

Experimental devices

Two approaches :

1- continuous 13C labeling platform
2- continuous CO2 exchange measurements

Labeling platform ($^{13}CO_2$)

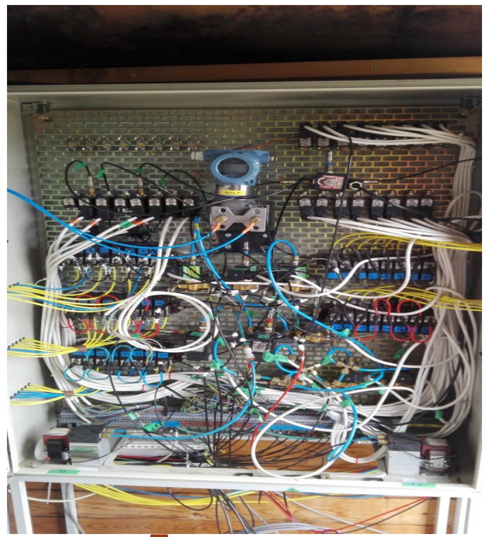
^{13}C-depleted CO_2 of fossil-fuel origin

Tracing source of respired carbon in presence of living plants

Follow humification and Rhizosphere Priming Effect

Experimental devices

Gaz exchanges measurements

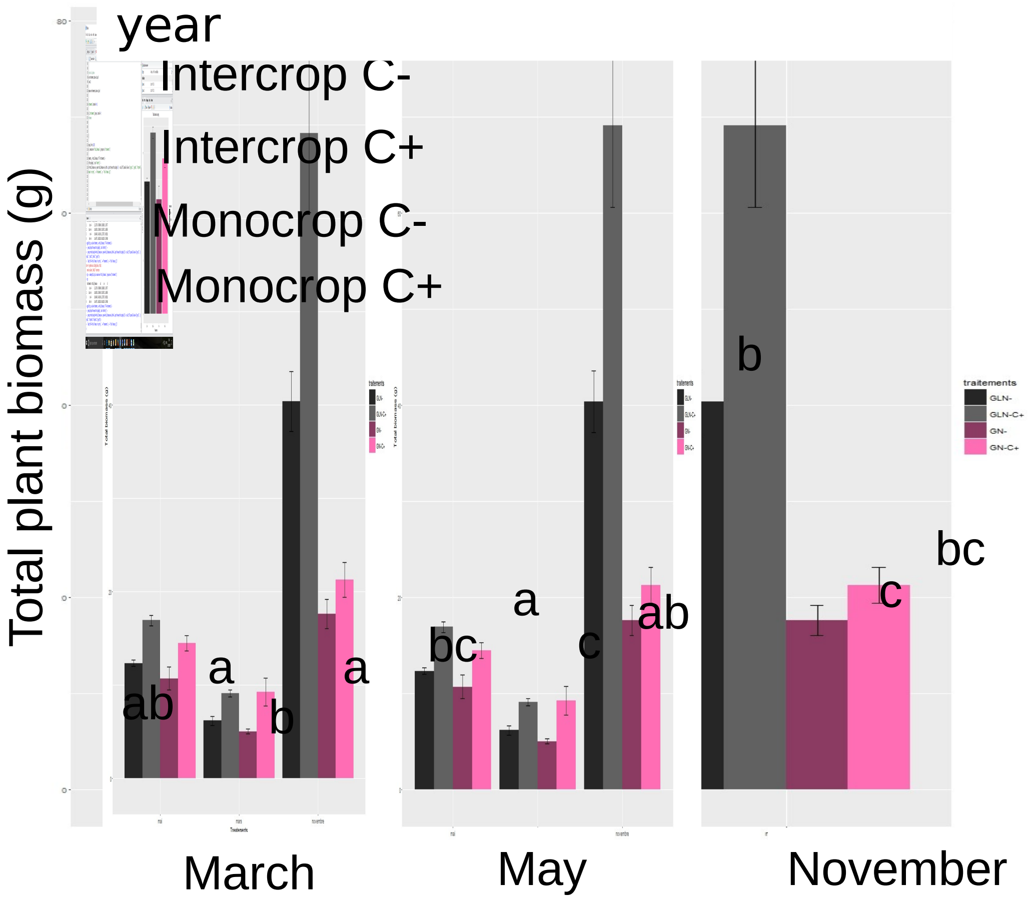


air flux

- Measure of differential CO2 each 30 minutes on each pots
- Calculation of net ecosystem exchange
- Deduction of ecosystem respiration and photosynthesis

Effect of eleveted CO2 on total plant production

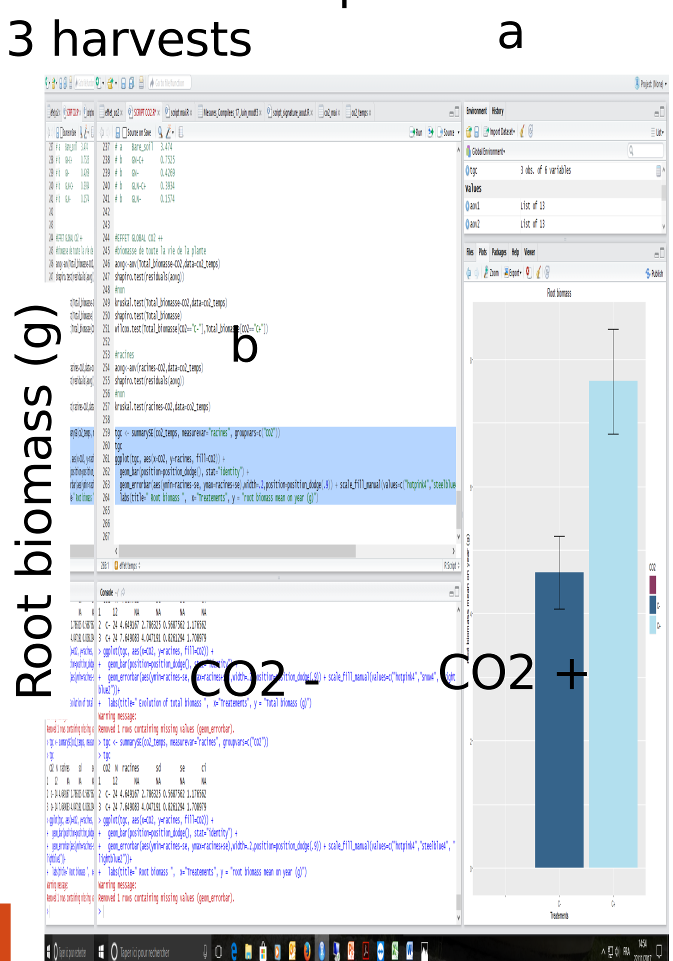
Shoot + root biomass along the year



- Globally higher plant production in elevated CO_2 (p-value=0,04)
- After summer, no significant difference in monocrop
- After one year, higher production in

Effect of eleveted CO_2 on roots production

Root biomass production including the 3 harvests

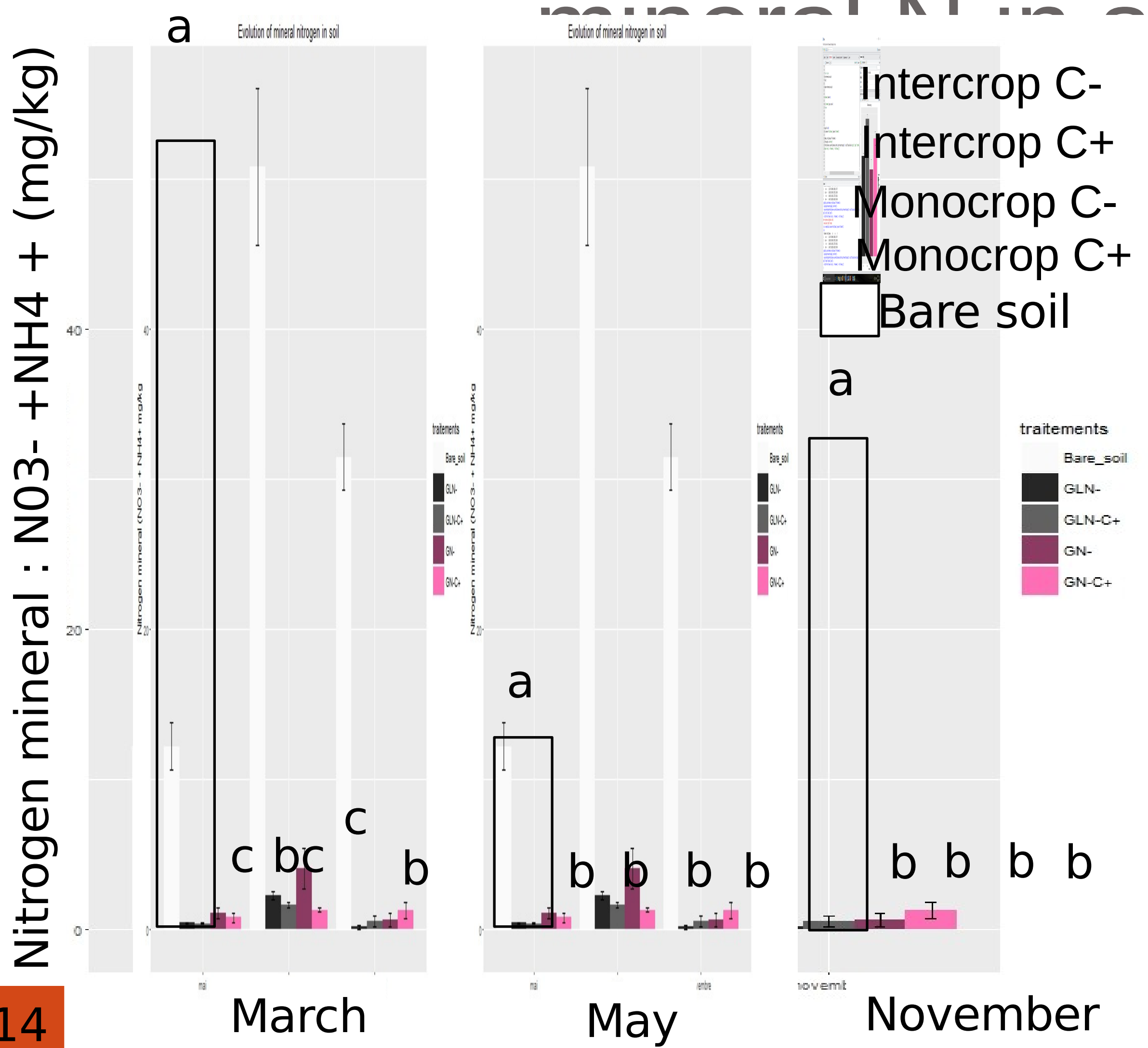


- On one year, higher root production in elevated CO_2 (p-value=0,002)

→ **The higher plant production is especially due to higher root investissment**

→ **Higher soil exploration in elevated CO_2**

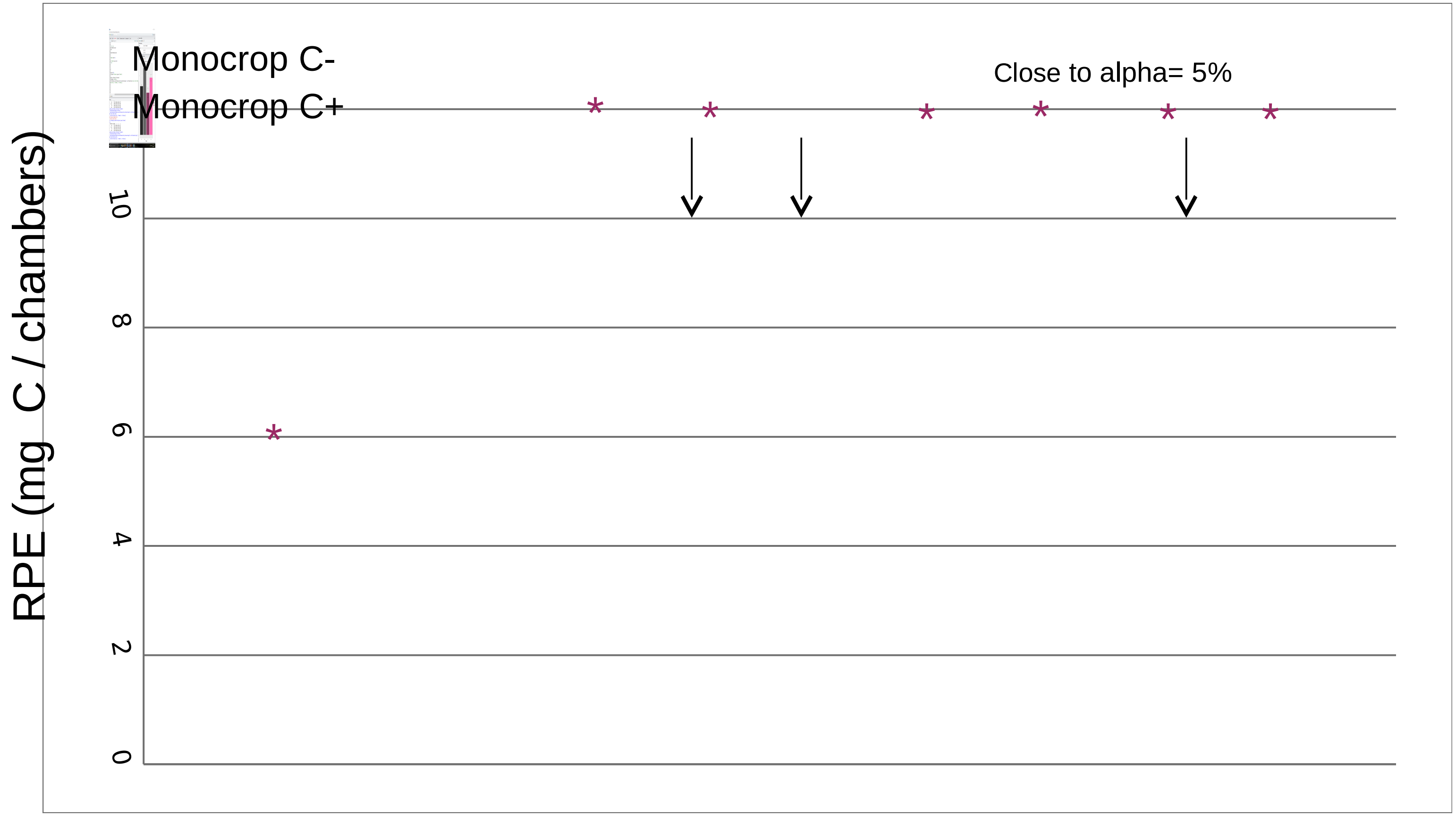
Consequences of root exploration on mineral N in soil



- Planted effect
- Fastly mineral N exhaustion in monocrop elevated CO_2

In november , absence of biomass difference due to N limitation ?

Consequences of N limitation on RPE

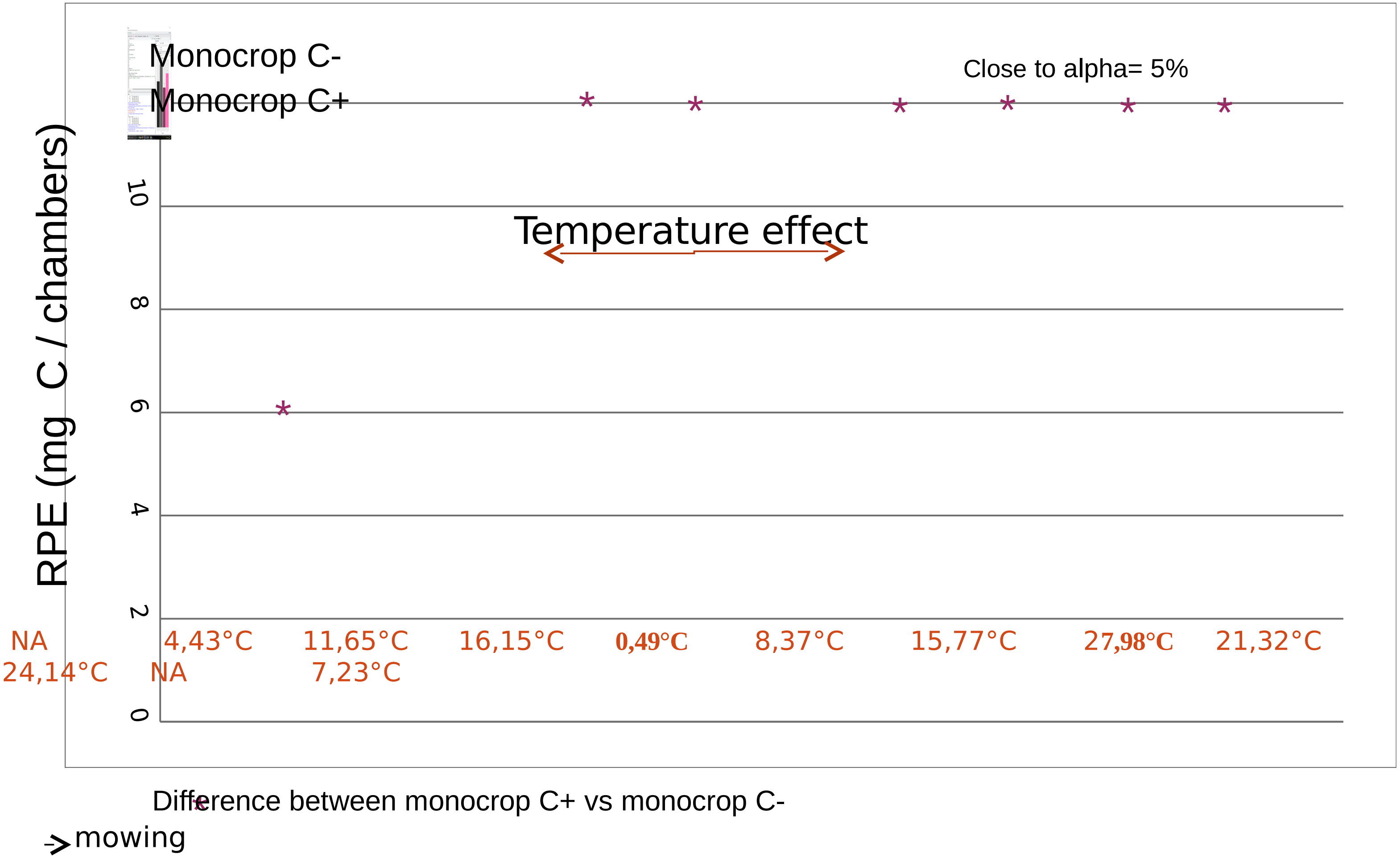


Difference between monocrop C+ vs monocrop C-

-> mowing

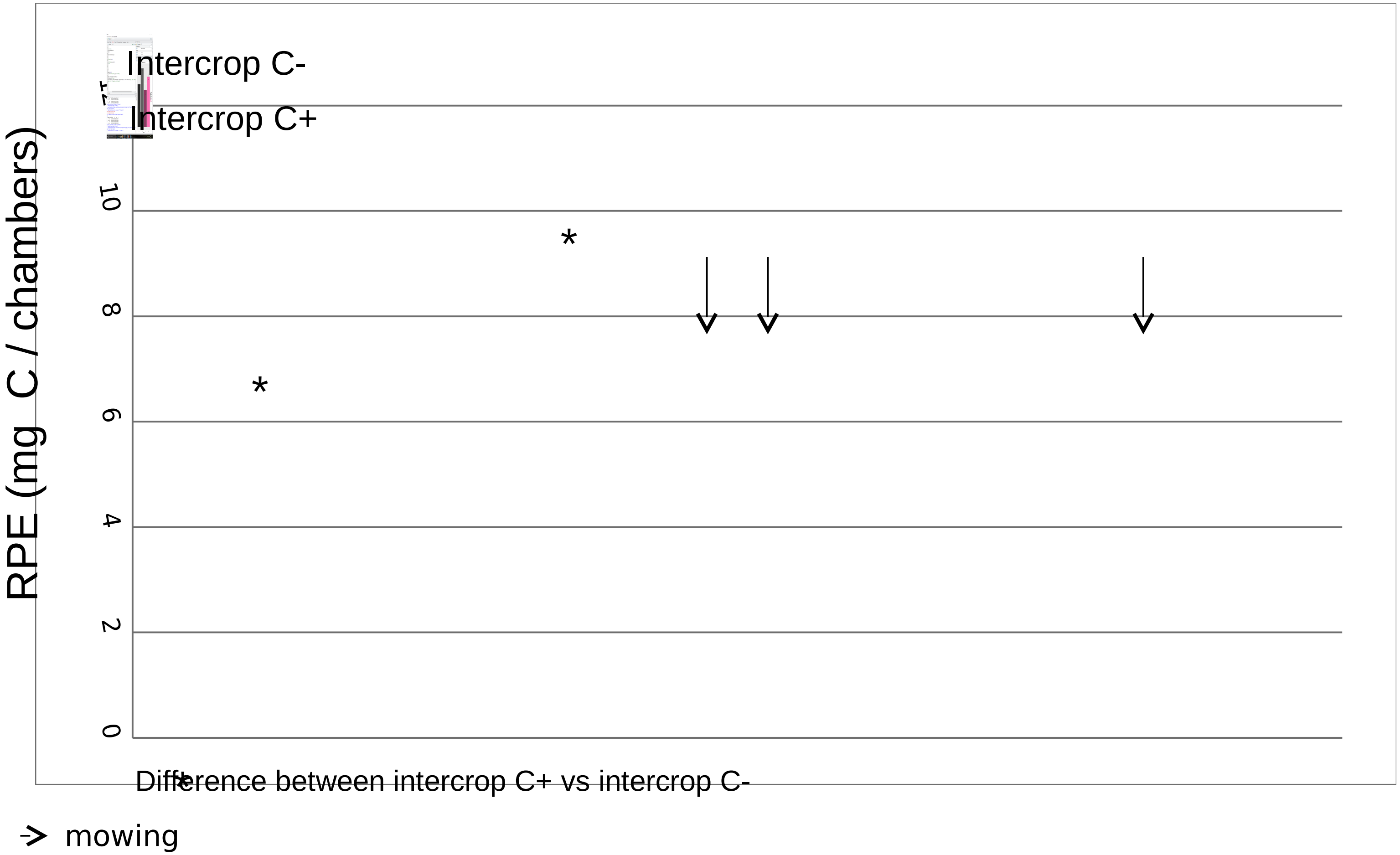
- Globally higher RPE in monocrop C+ compared to monocrop C-

Consequences of N limitation on RPE



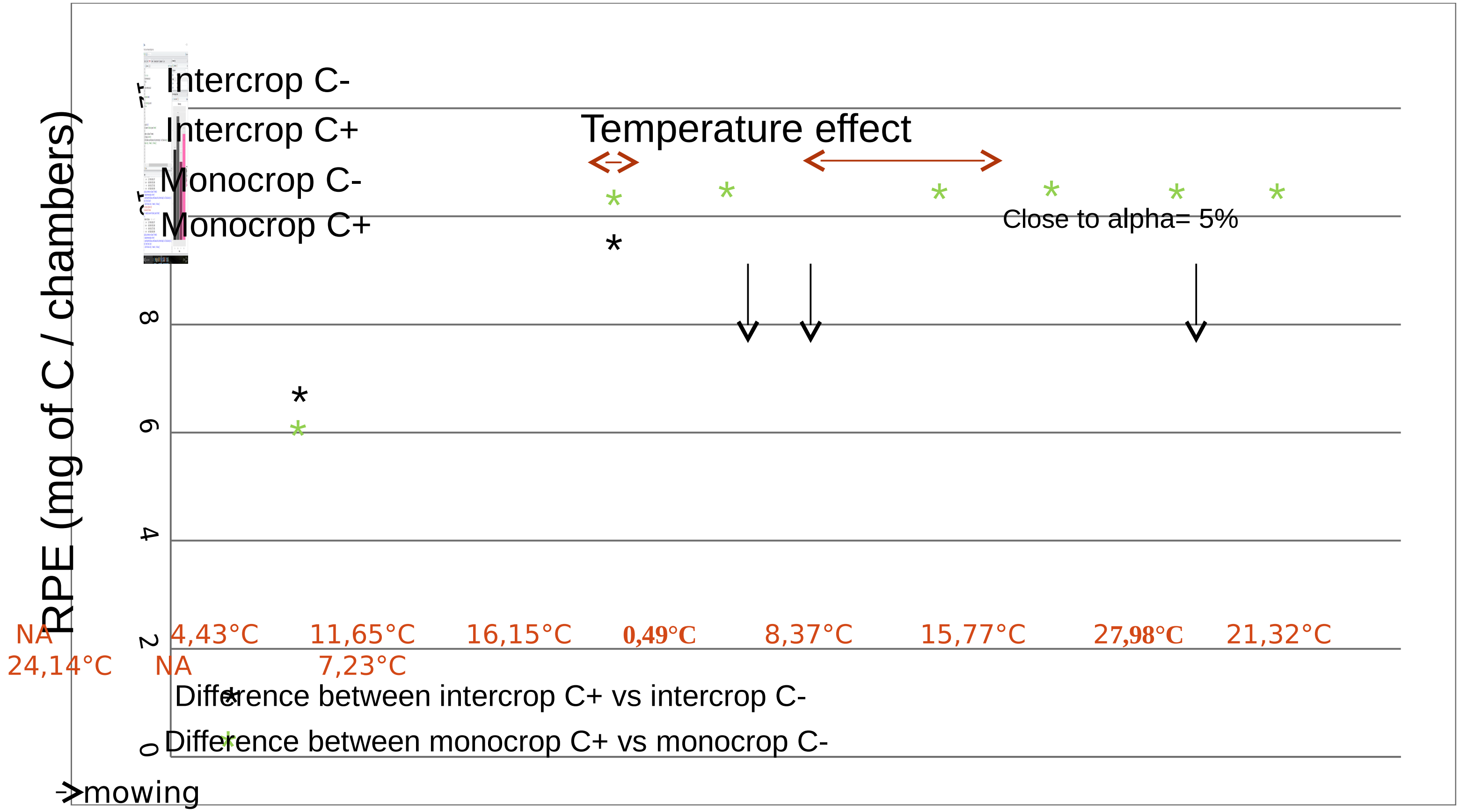
- Globally higher RPE in monocrop C+ compared to monocrop C-
- Sensitivity of extreme temperature higher in monocrop C+ compared to monocrop C-

Consequences of N limitation on RPE



- Globally no difference of RPE in intercrop

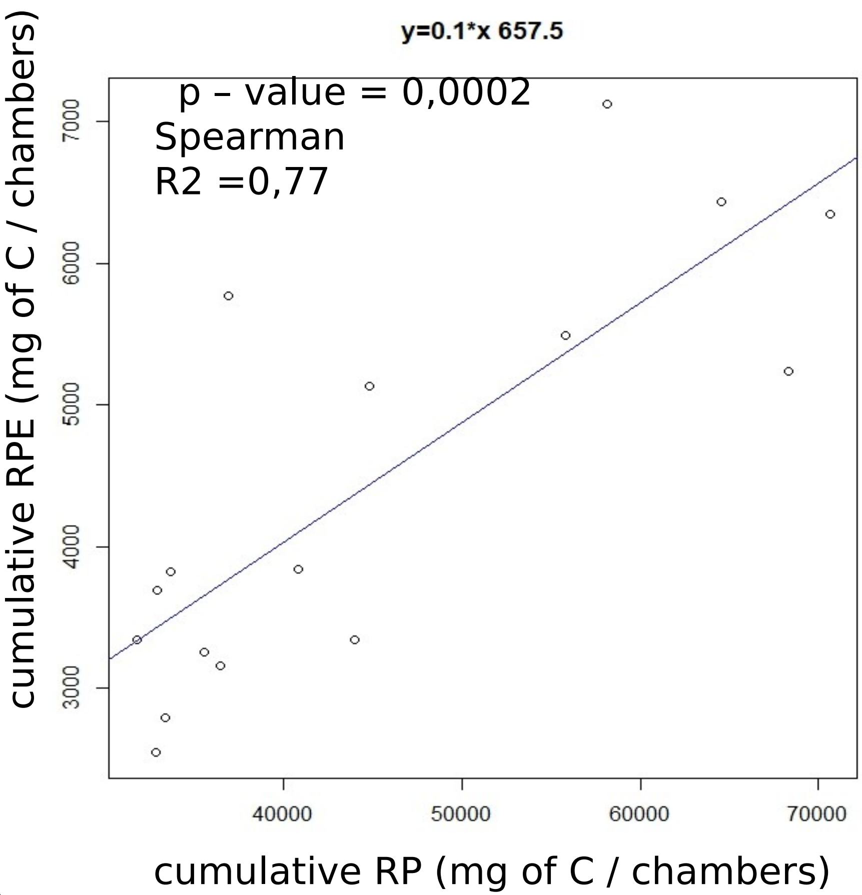
Consequences of N limitation on RPE



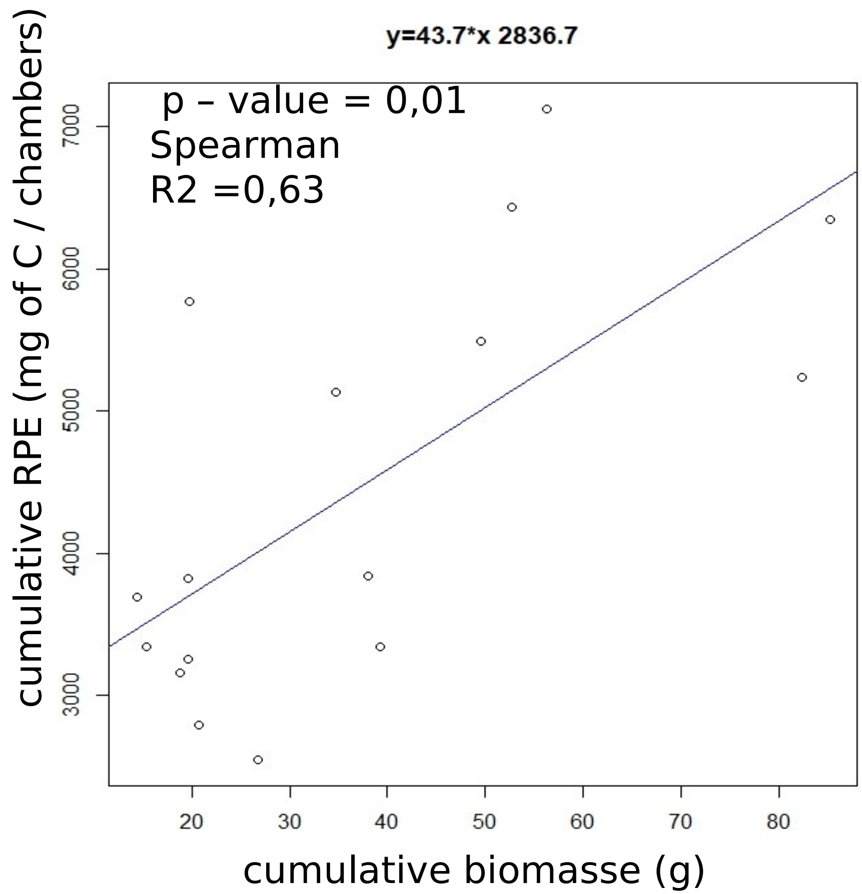
 N limitation in elevated CO2 induce more RPE in ryegrass monoculture depending on season

Correlation between photosynthesis proxy and RPE

cumulative RP vs cumulative RPE



cumulative biomass vs cumulative RPE



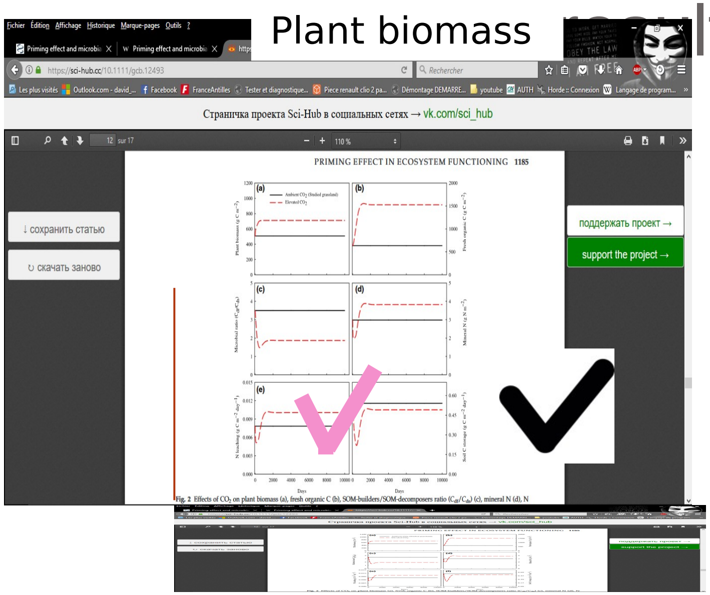
More biomass = more RPE

Destocking in monocrop elevated CO2

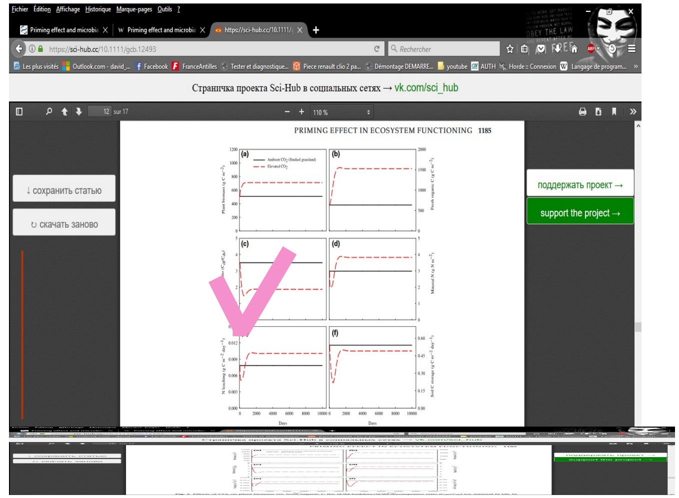
Conclusion

…lts in f… f others papers

Plant biomass



Mineral N

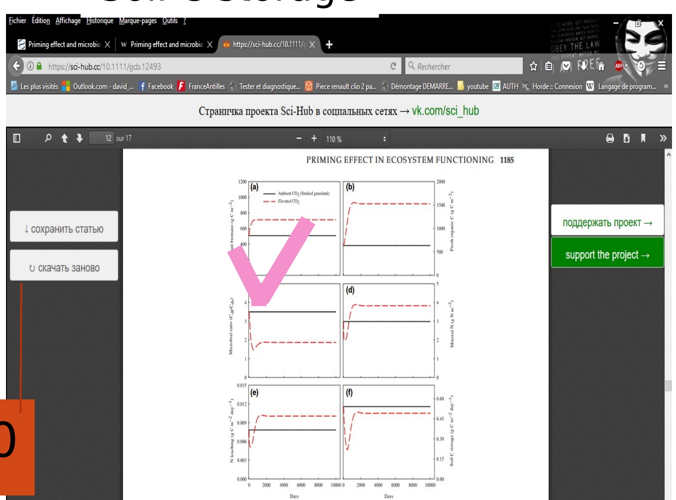


Effect of elevated CO2 in adequation

- In monocrop
- In intercop

dapted from Perveen *et al.*, 2014

Soil C storage

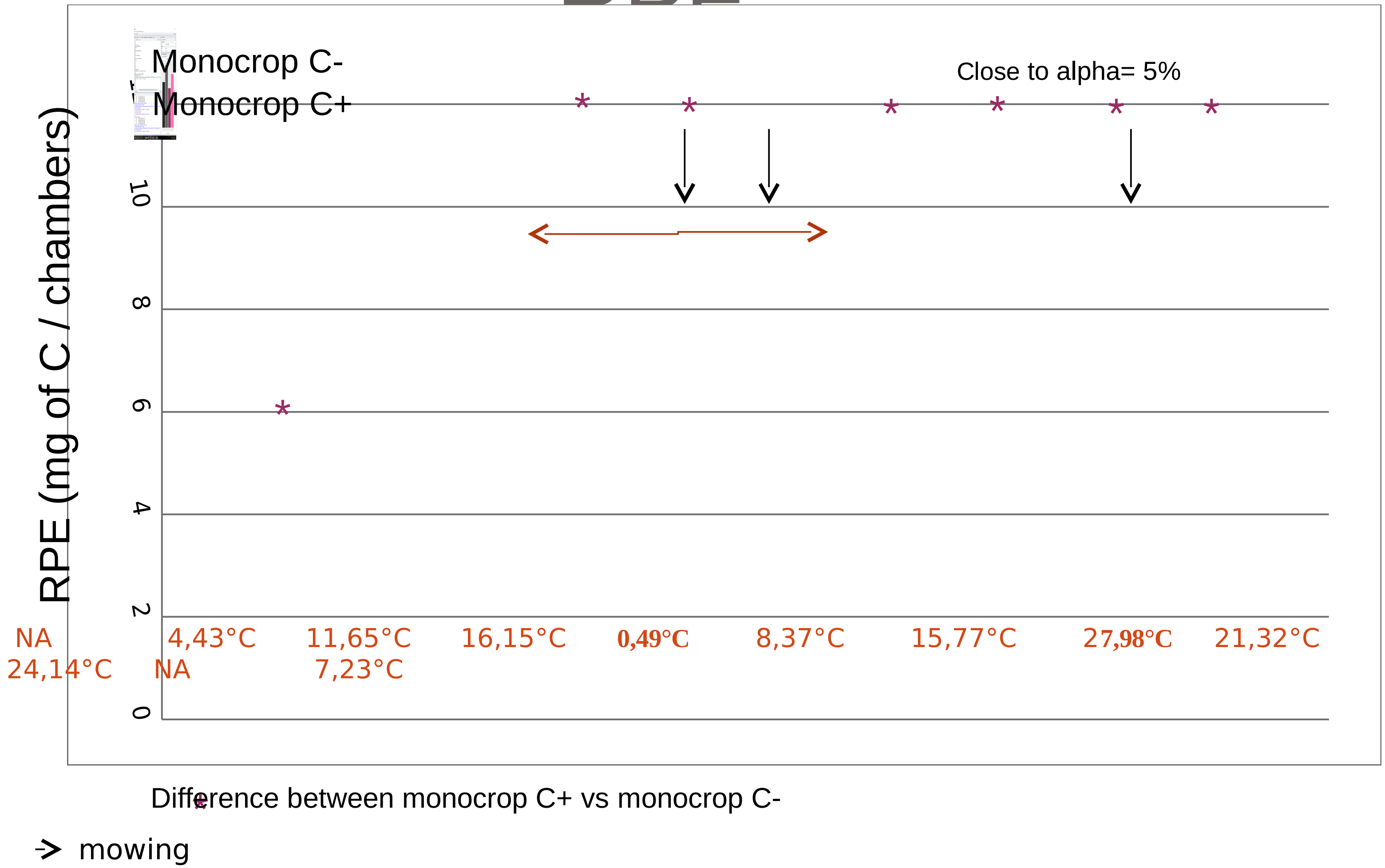


- In long term, increase of SOM decomposition decrease of soil stock
- Attenuation with legumes

Hu *et al.*, 2001; Dijsktra *et al.*, 2013; Perveen *et al.*, 2014; Nie *et al.*, 2016; Vestergard *et al.*, 2016;

Thank for your attention

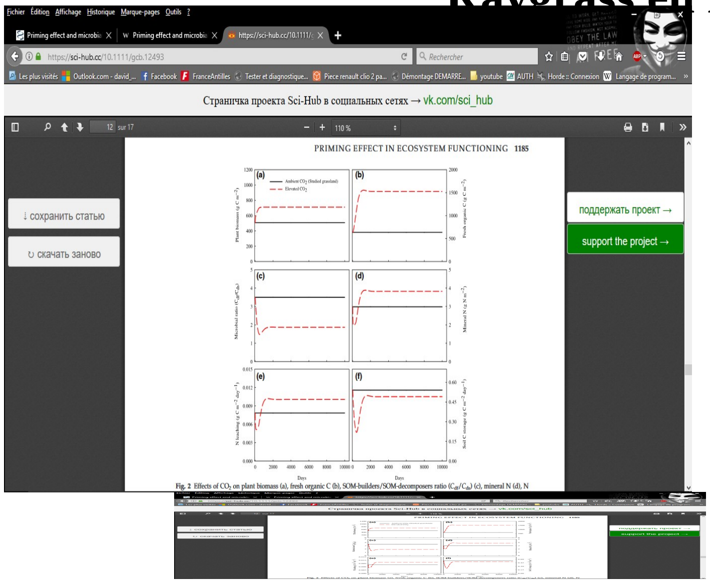
Consequences of N limitation on RPE



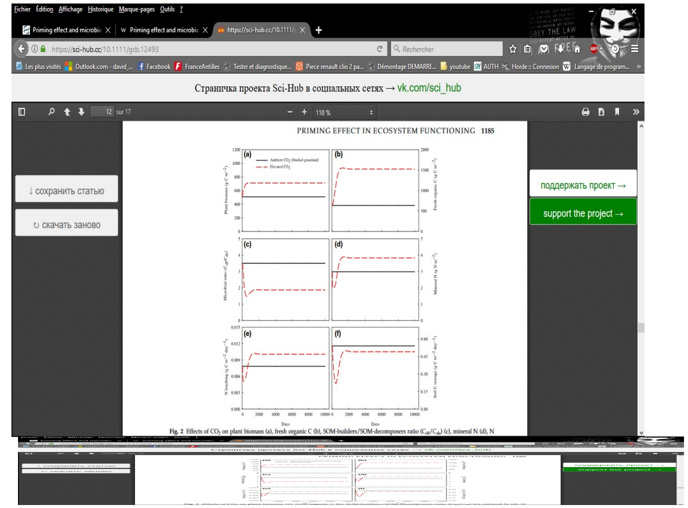
- Globally higher RPE in monocrop C+ compared to monocrop C-
- Sensitivity of extreme temperature higher in monocrop C+ compared to monocrop C-

Matching with the model ?

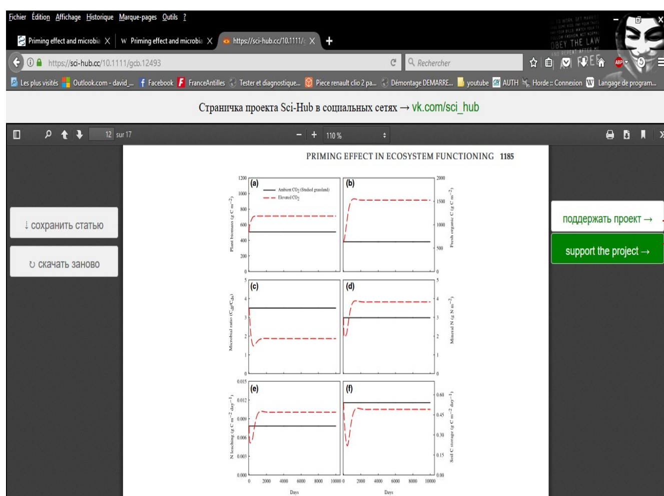
Raygrass en monoculture



Mitigé: sensibilité chaleur
Remise en question du choix de l'espèce



Oui au départ puis seulement tendance
Suit-on la courbe ? Récolte novembre

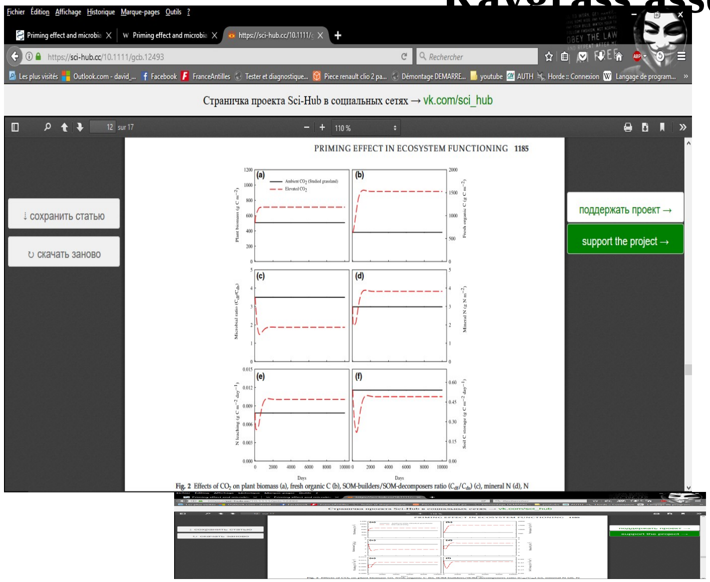


Résultats de bilan de C important
MAIS
Décomposition SOM plus élevée en CO2+ hormis été

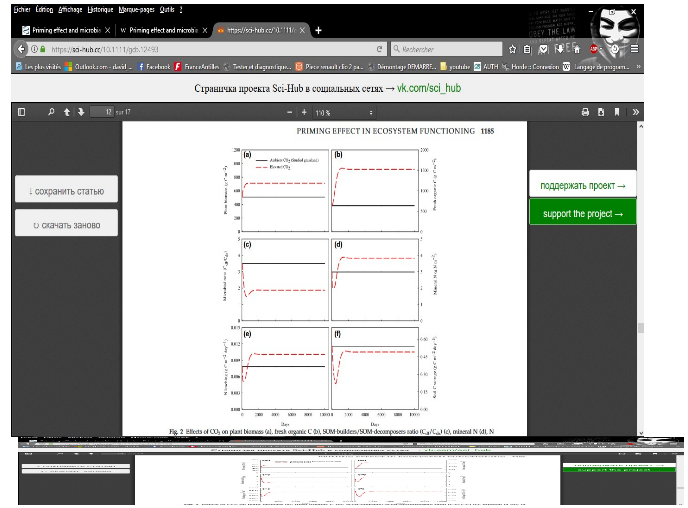
en *et al.*, 2014

Matching with the model ?

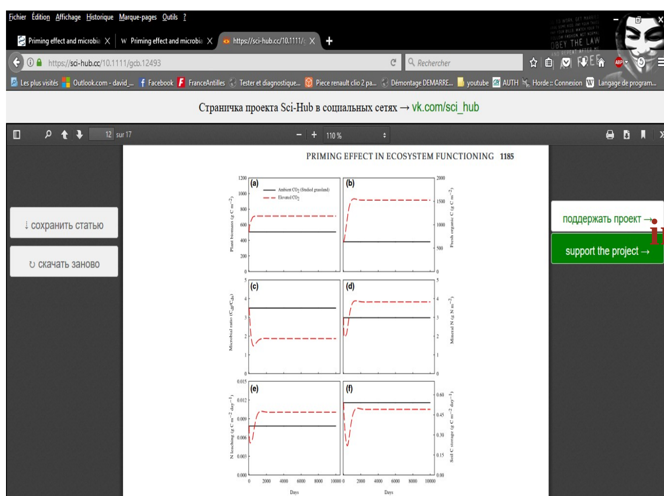
Raygrass associé au trèfle



Biomasse très élevée en CO2+



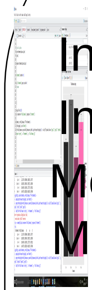
Aucune différence
Fixation symbiotique du N atténuation



Résultats de bilan de C important
MAIS
implantation trèfle, décomposition SOM pas différente
+
Biomasse très élevé
STOCKAGE ??

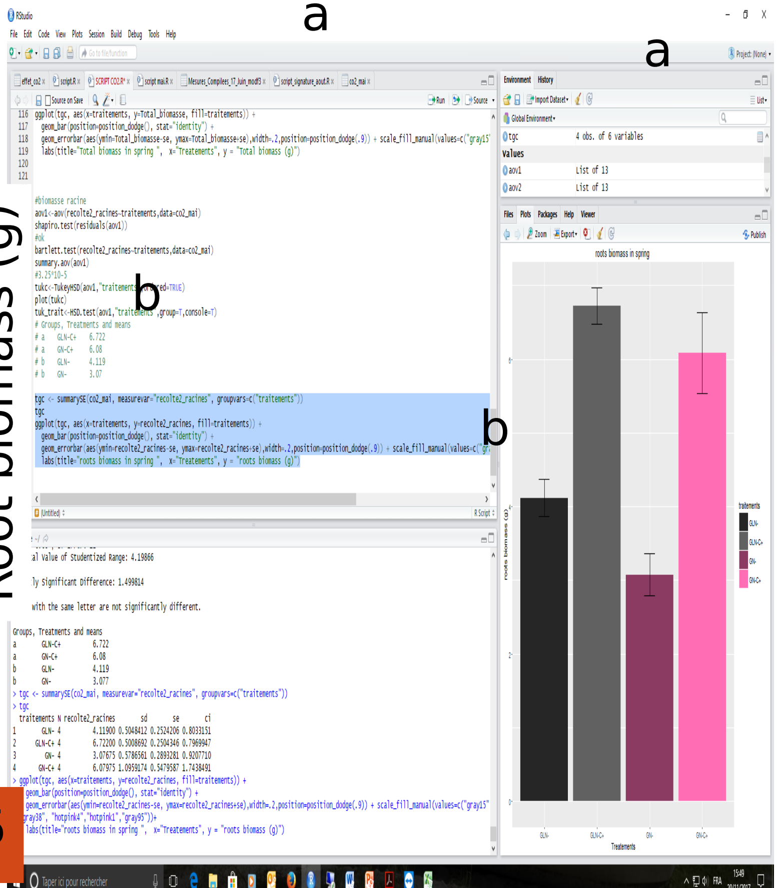
en *et al.*, 2014

Effect of eleveted CO2 on roots production



Intercrop C-
Intercrop C+
Monocrop C-
Monocrop C+

Exemple of root biomass in srping



- On one year, higher root production in elevated CO_2 (p-value=0,002)