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SIGNAL Sustainable intensification of agriculture through agroforestry

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First application of low-cost eddy covariance for CO_2 fluxes over agroforestry

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Introduction | **Methods** | **Results** | **Conclusions**

Objectives | Low-cost eddy covariance | CO_2 fluxes | References

Agroforestry | Custom made housing | Latent heat flux + Sensible heat flux

Locations | CO_2 sensor

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Introduction

Motivation: Agroforestry is a combination of monoculture agriculture and trees. Agroforestry has been shown to alter the microclimate, productivity, and nutrient and water usage – as compared to standard agricultural practice. The, potentially, higher carbon (C) sequestration of agroforestry, relative to monoculture systems, provides an interesting option for mitigating climate change, highlighting the need for improved study of agroforestry systems.

Challenge: Studies of net ecosystem exchange of CO_2 (NEE) of agroforestry systems are rare, in comparison to the extensive studies of NEE of agricultural systems (croplands and grasslands).

Research aim: The current study, as part of the SIGNAL (sustainable intensification of agriculture through agroforestry) project, investigates NEE of agroforestry compared to that of monoculture agriculture.

Objectives

Agroforestry

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Objectives

- Does agroforestry sequester more CO_2 from the air compared to monoculture agriculture?
    - Can agroforestry contribute in mitigating climate change?
    - Measuring and assessing the half-hourly Net Ecosystem Exchange (NEE) of agroforestry and monoculture.

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Agroforestry (alley cropping)

Why agroforestry?

Possible effects of agroforestry:

- **Higher carbon sequestration (Fig. 1)**
- Better microclimate
- Higher productivity
- More efficient nutrient usage
- More efficient water usage
- Higher water use efficiency
- Wind reduction
- (Wind/water) erosion reduction

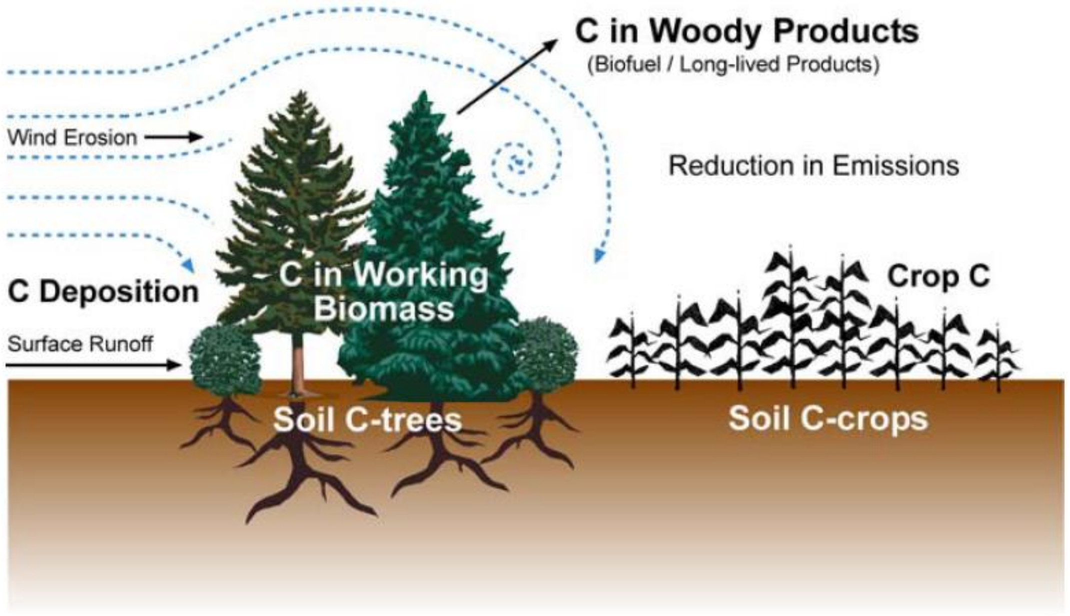

Figure 1: Carbon sequestration in agroforestry, from [1]

[1] M.M. Schoeneberger, "Agroforestry: working trees for sequestering carbon on agricultural lands", Agroforestry Systems, 2009.

Introduction
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Picture from the SIGNAL agroforestry plot in Forst. Made by Marcus Schmidt.

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SIGNAL Sustainable intensification of agriculture through agroforestry

Locations

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http://www.signal.uni-goettingen.de/

This project is part of SIGNAL: "Sustainable intensification of agriculture through agroforestry". SIGNAL belongs to the German initiative BONARES, which focusses on sustainable use of soils as a limited resource. This study is part of phase 2 (2018-2021), phase 1 took place from 2015-2018.

- Five locations in Germany
- Each location has an agroforestry and adjacent reference monoculture site

Figure 2: Locations of SIGNAL in Germany

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Methods

The study employs paired comparisons of flux measurements above agroforestry and monoculture agronomy. Each agroforestry and adjacent reference site has each own eddy-covariance flux tower. So 10 in total.

Monoculture

Eddy covariance setup

Locations

- Towers: 3.5 and 10 m high (Exception: Vechta, both 5m)
- 4 Cropland sites
- 1 Grassland site
- (Fast growing)Trees
  - Poplar
  - Willow
  - Robinia
- Each site is powered by solar panels

Agroforestry

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Low-cost eddy covariance flux towers

What is being measured at each station?

- Eddy covariance measurements:
  - CO_2 flux - Net Ecosystem Exchange (NEE)
  - Latent heat flux (LE), Evapotranspiration (LE)
  - Sensible heat flux (H)

- Meteorological measurements:
  - 3D wind speed and direction (uSONIC-3 Omni, Metek), temperature, relative humidity, precipitation, air pressure, radiation (net, short and longwave) and ground heat flux.

Custom made housing
Low cost CO_2 sensor
Low cost H_2O sensors (ET/WPL)
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Custom made housing

The custom made housing is built as described in detail by Hill et al. (2017) [2] and produced by the University of Exeter (Robert Clement and Timothy Hill).

The housing includes the following parts:

- Low cost CO_2 sensor (GMP343, Vaisala)
- Low cost RH sensor (HIH-4000, Honeywell)
- Temperature sensor (Thermocouple)
- Pump to control the flow through the enclosed set-up.
- Varying to the tower: 3.5, 5 or 10m length of pipe (Ø 4mm) to sample the air next to the sonic anemometer.

[2] T. Hill, M. Chocholek, and R. Clement, "The case for increasing the statistical power of eddy covariance ecosystem studies: why, where and how?", Global Change Biology, 2017.

Low cost CO_2 sensor

Low cost H_2O sensors

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Low cost CO_2 sensor: GMP343, Vaisala

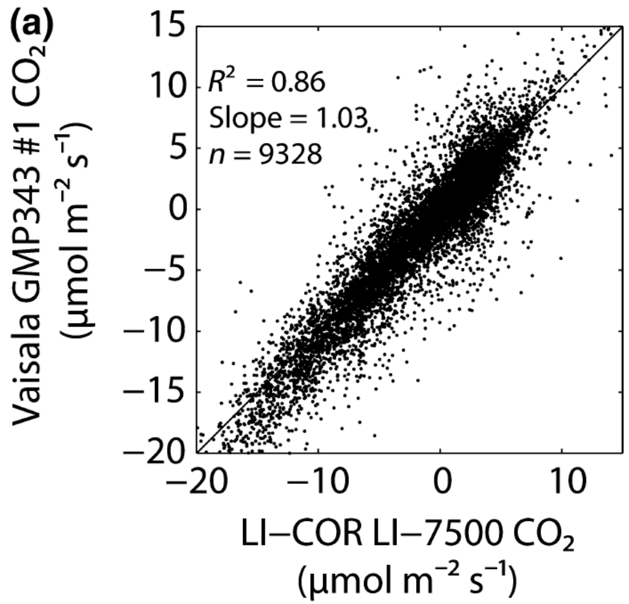
The measurements are performed with low-cost CO_2 sensors (GMP343, Vaisala). These sensors have been successfully tested for eddy covariance measurements above grassland by Hill et al. (2017), Fig. 3.

Additionally, this study will verify the performance above cropland, grassland and agroforestry by comparing fluxes from the GMP343 (Vaisala) with LI-7200 (LI-COR) gas analyzers.

Key specifications of the GMP343:

- Range: 0-1000ppm
- Accuracy: ± 3ppm + 1% of reading
- Precision (repeatability): ± 3ppm
- Response time: ~2 sec

Figure 3: Half hourly corrected fluxes, from [2]



Link to specs sensor (PDF)

Custom made housing

[2] T. Hill, M. Chocholek, and R. Clement, "The case for increasing the statistical power of eddy covariance ecosystem studies: why, where and how?", Global Change Biology, 2017.

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Low cost H_2O sensors

1. Included into the CO_2 custom made housing – used for WPL correction

- HIH-4000 relative humidity sensor (Honeywell) – ~2sec response time
- Integrated into the custom made housing, inside the cell where CO_2 and temperature is measured.
- Positively tested by Hill et al. (2017) [2]

2. Additional separate from the CO_2 measurement setup – used for separate evapotranspiration measurements

- BME280 (Bosch) – 8 Hz sampling frequency and response time of ~3sec
- Relative humidity, temperature and pressure
- Positively tested in SIGNAL (phase 1) by Markwitz et al. (2019) [3]

Custom made housing

[2] T. Hill, M. Chocholek, and R. Clement, “The case for increasing the statistical power of eddy covariance ecosystem studies: why, where and how?“, Global Change Biology, 2017.

[3] C. Markwitz and L. Siebicke, “Low-cost eddy covariance: a case study of evapotranspiration over agroforestry in Germany”, Atmos. Meas. Tech., 2019.

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Results

- Continuous data series from mid-summer (2019) until winter 2019/2020 show that both agricultural systems acted as a sink with comparable fluxes during summer.
- The diurnal CO_2 cycle and the response to harvest is distinguishable.
- Preliminary results suggest a small difference in cumulative fluxes between the two systems.

For all the data shown:

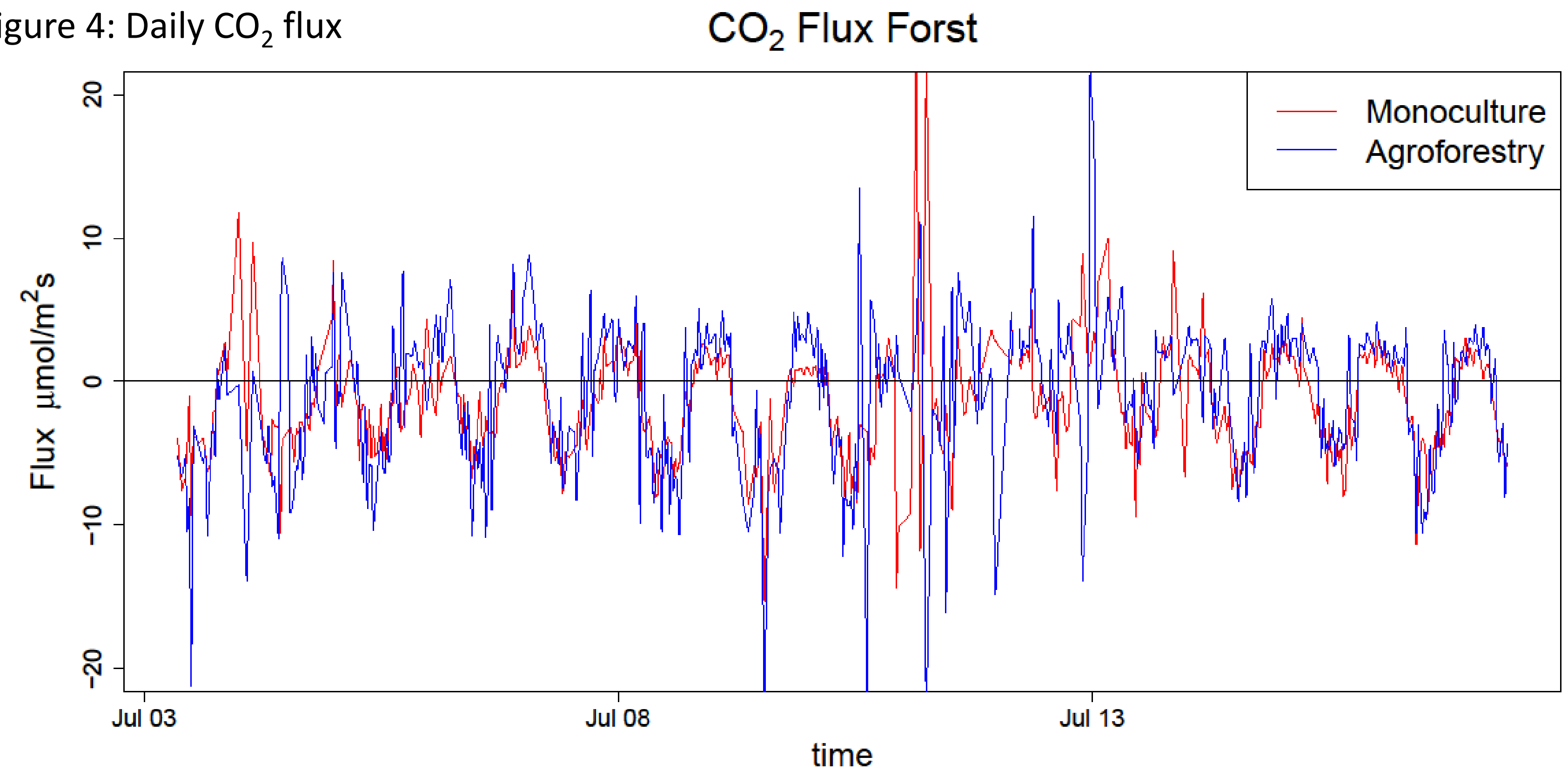
- Quality check CO_2 data, using ≤ 1 according to 0-1-2 system (Mauder and Foken, 2004).
- High and low filter to filter out (unrealistic) peaks.
- No gap filling has been performed yet.

Diurnal cycles Forst

Mean diurnal cycle of CO_2 flux for this period

- The diurnal CO_2 cycle is clearly visible, however we also experience days with noise in our data.

Figure 4: Daily CO_2 flux



Results | Cumulative CO_2 flux | Latent + sensible heat flux | CO_2 flux Vechta | Home

Diurnal cycle Forst – Mean and SD

- For the two week time period of Figure the diurnal CO_2 cycle is also clearly visible in the mean diurnal cycle.
- Both system show similar behavior.

Results

Cumulative CO_2 flux

Latent + sensible heat flux

CO_2 flux Vechta

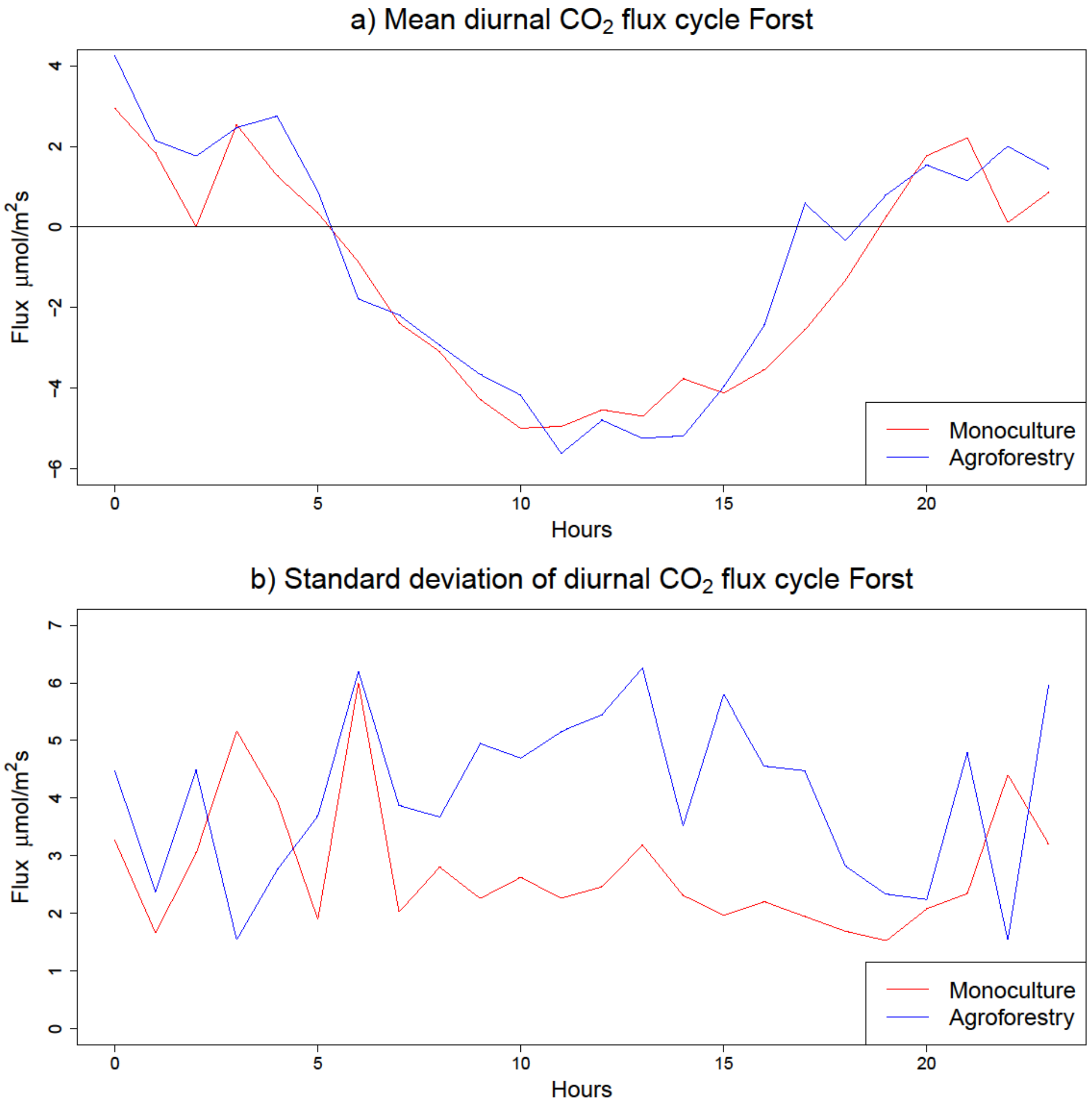


Figure 5: a) Mean diurnal CO_2 cycle (NEE), b) Standard deviation of diurnal CO_2 cycle.

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CO_2 Fluxes Forst (Lausitz)

- From July 2019 to January 2020 the agroforestry seems to sequester more carbon then the monoculture site.
- Response to the harvest of barley is visible.

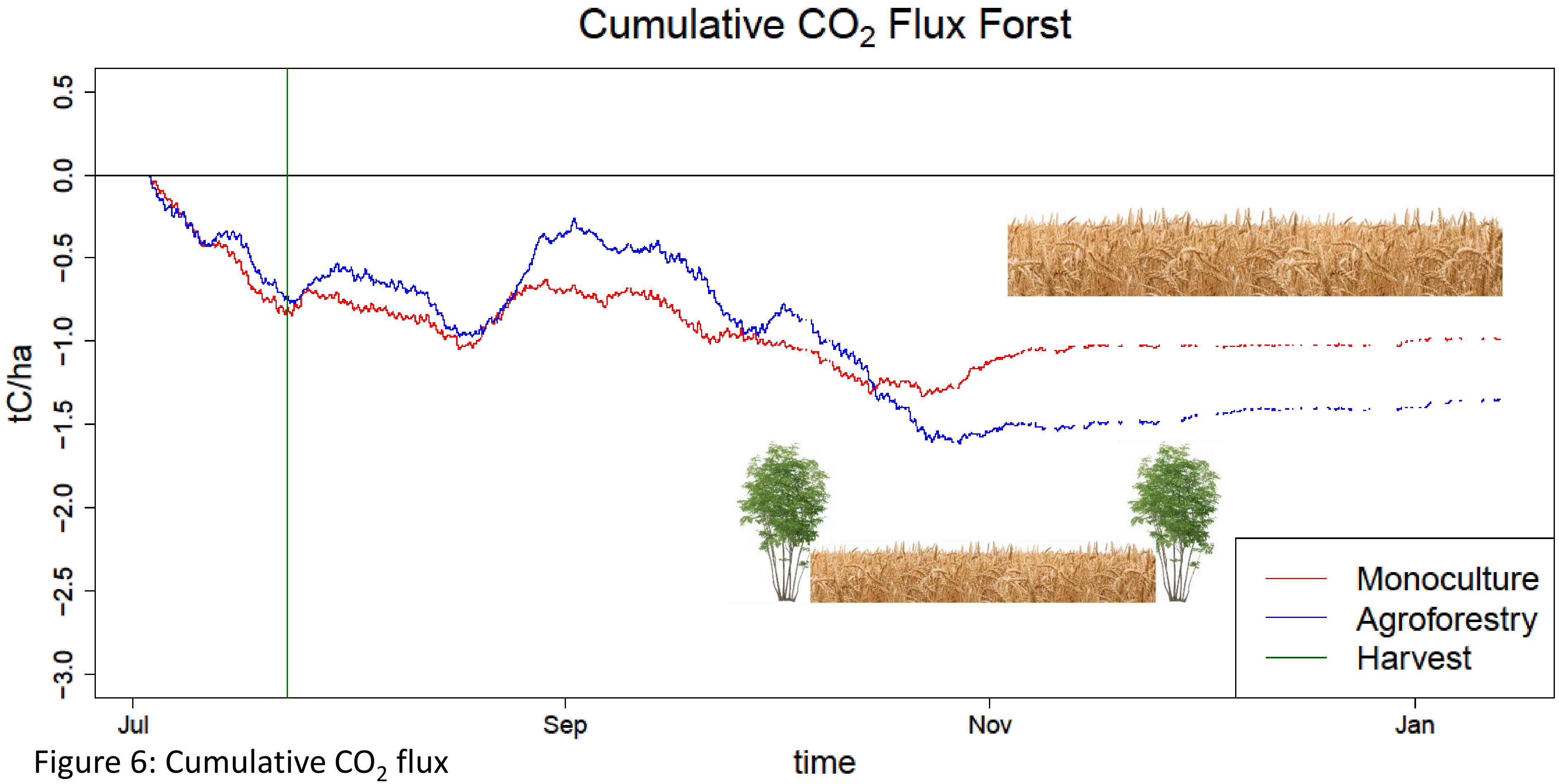

Figure 6: Cumulative CO_2 flux

Results | Diurnal cycles CO_2 flux | Latent + sensible heat flux | CO_2 flux Vechta

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Latent heat (LE) and Sensible heat (H) flux Forst

- The latent heat flux of the monoculture site is much bigger compared to the agroforestry site.
- The sensible heat flux of the agroforestry site is bigger compared to the monoculture site.

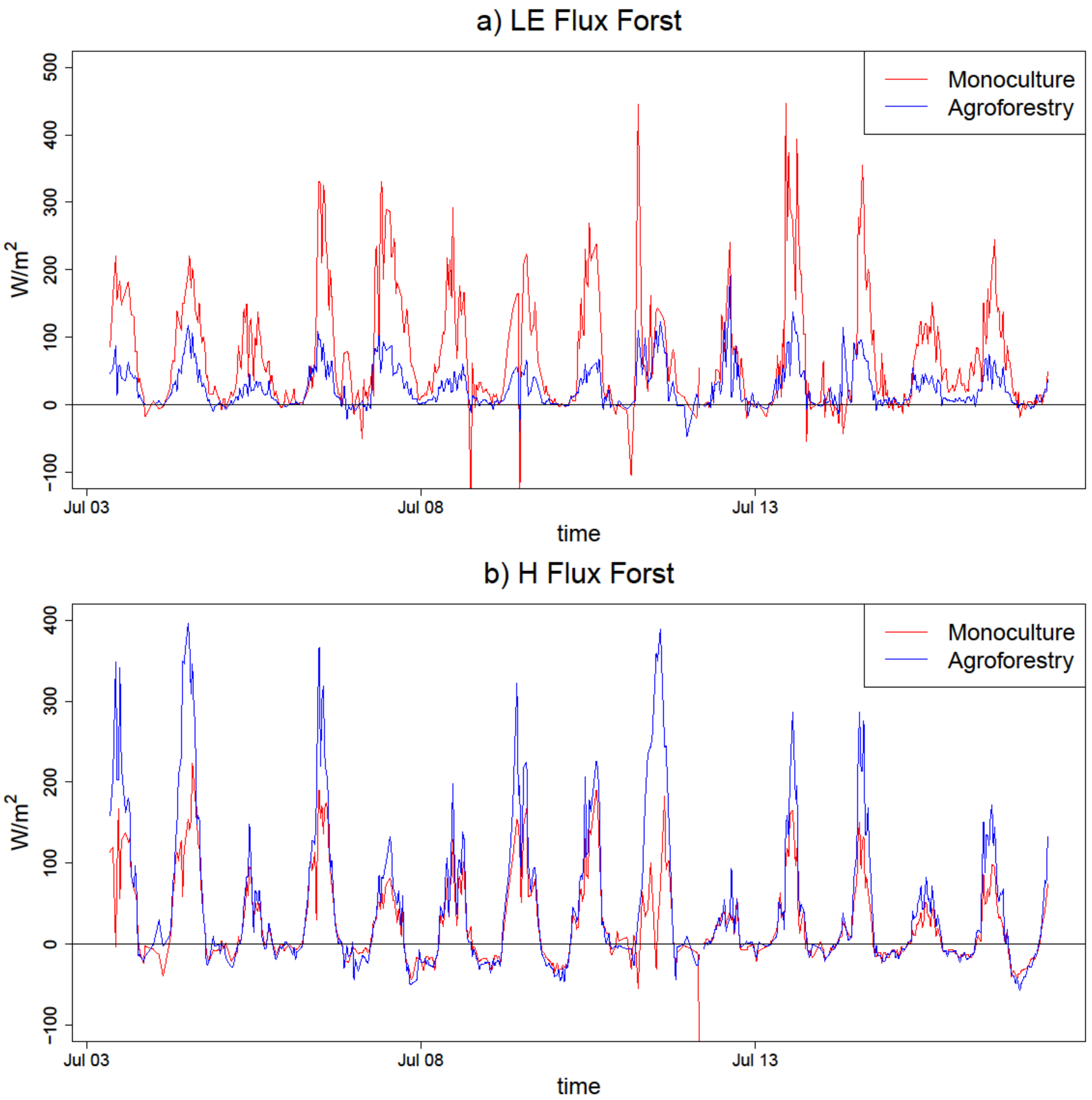

Figure 7: a) Daily latent heat flux, b) Daily sensible heat flux.

Results

Diurnal cycles CO_2 flux

Cumulative CO_2 flux

CO_2 flux Vechta

LE + H Vechta

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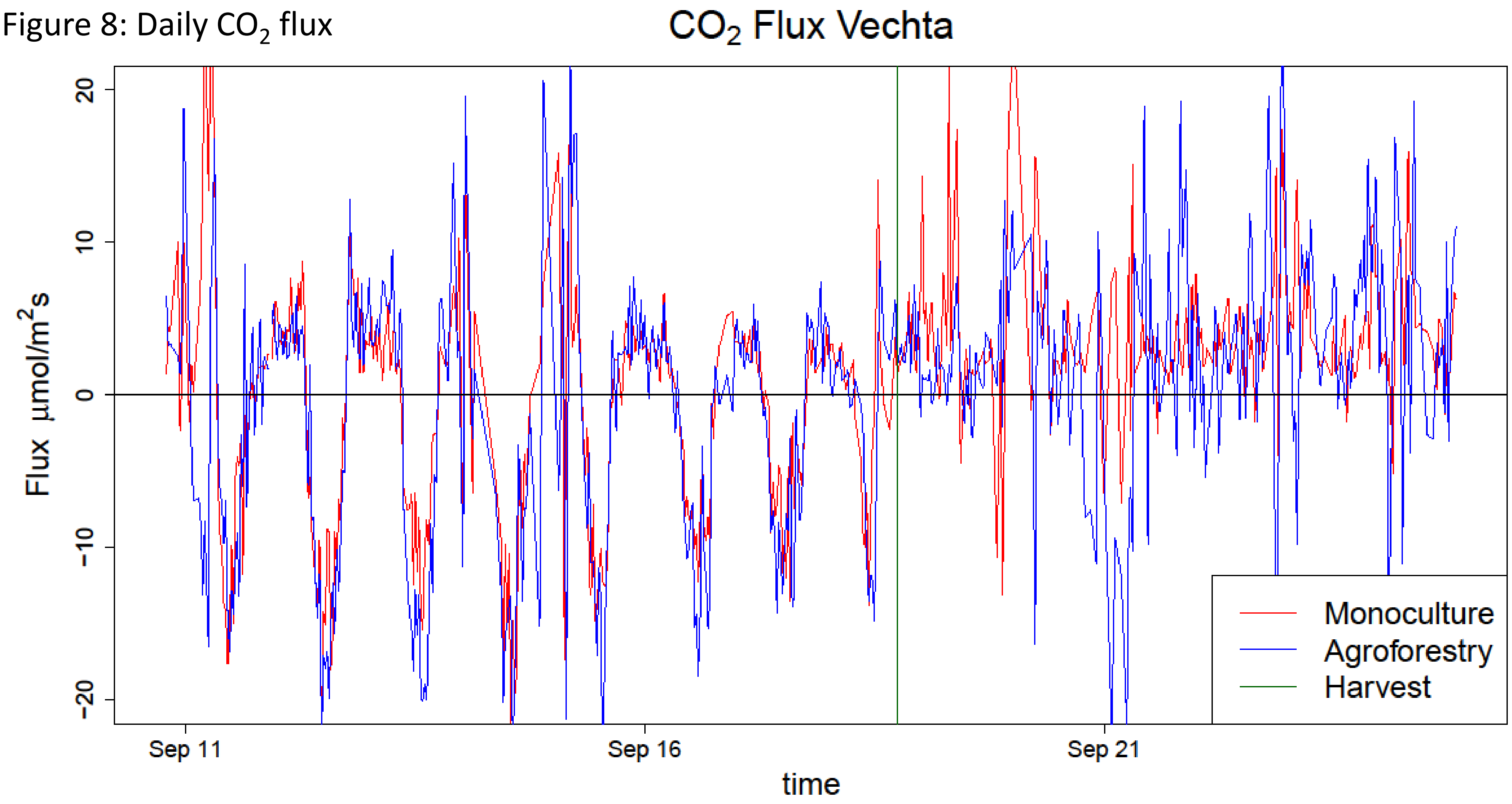
Diurnal cycles Vechta

- The diurnal CO_2 cycle is clearly visible until harvest.
- After harvest of the corn we experience more noise and less clear diurnal cycles.

Figure 8: Daily CO_2 flux

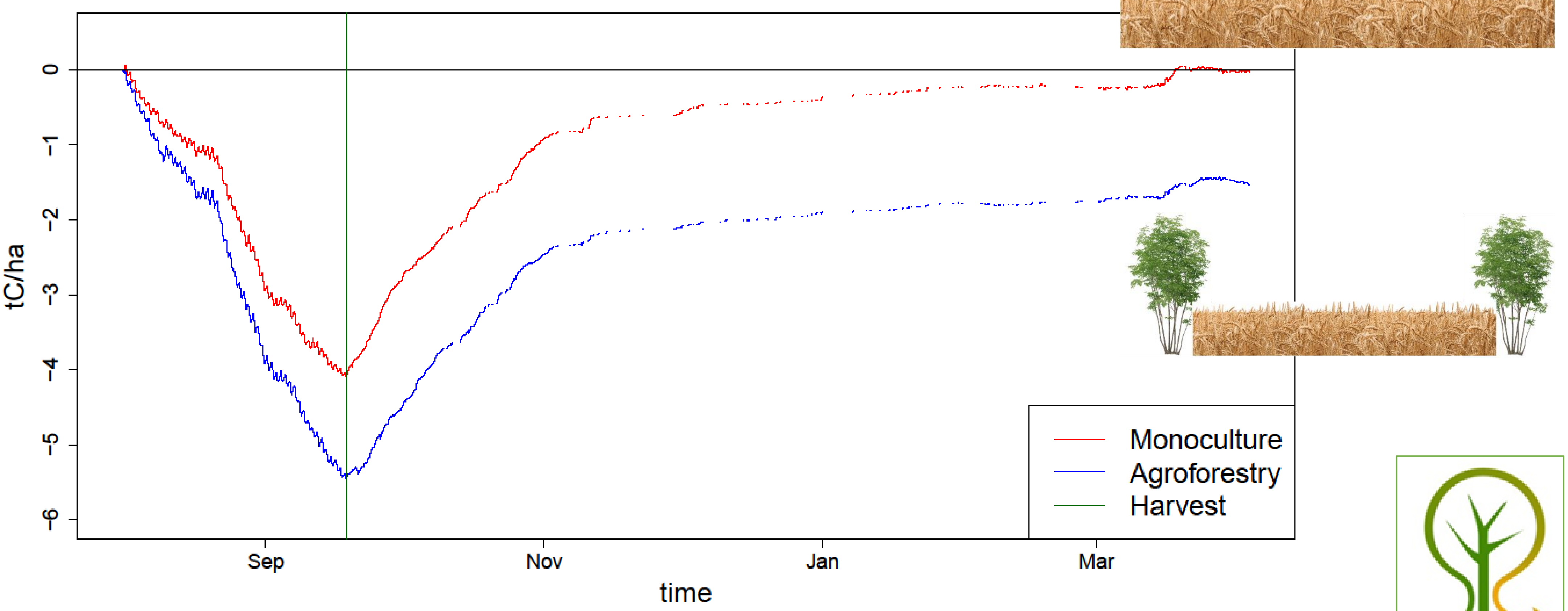


Results | Cumulative CO_2 flux | Latent + sensible heat flux | CO_2 flux Forst | Home

CO_2 Fluxes Vechta

- From August 2019 to March 2020 the agroforestry seems to sequester more carbon then the monoculture site.
- Response to the harvest of corn is clearly visible.

Figure 9: Cumulative CO_2 flux



Results
Diurnal cycles CO_2 flux
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Latent heat (LE) and Sensible heat (H) flux Vechta

- The latent heat flux of the agroforestry clearly changes after the harvest of the corn.
- The sensible heat flux stays similar.

Results

Cumulative CO_2 flux

Diurnal cycles CO_2 flux

CO_2 flux Forst

LE + H Forst

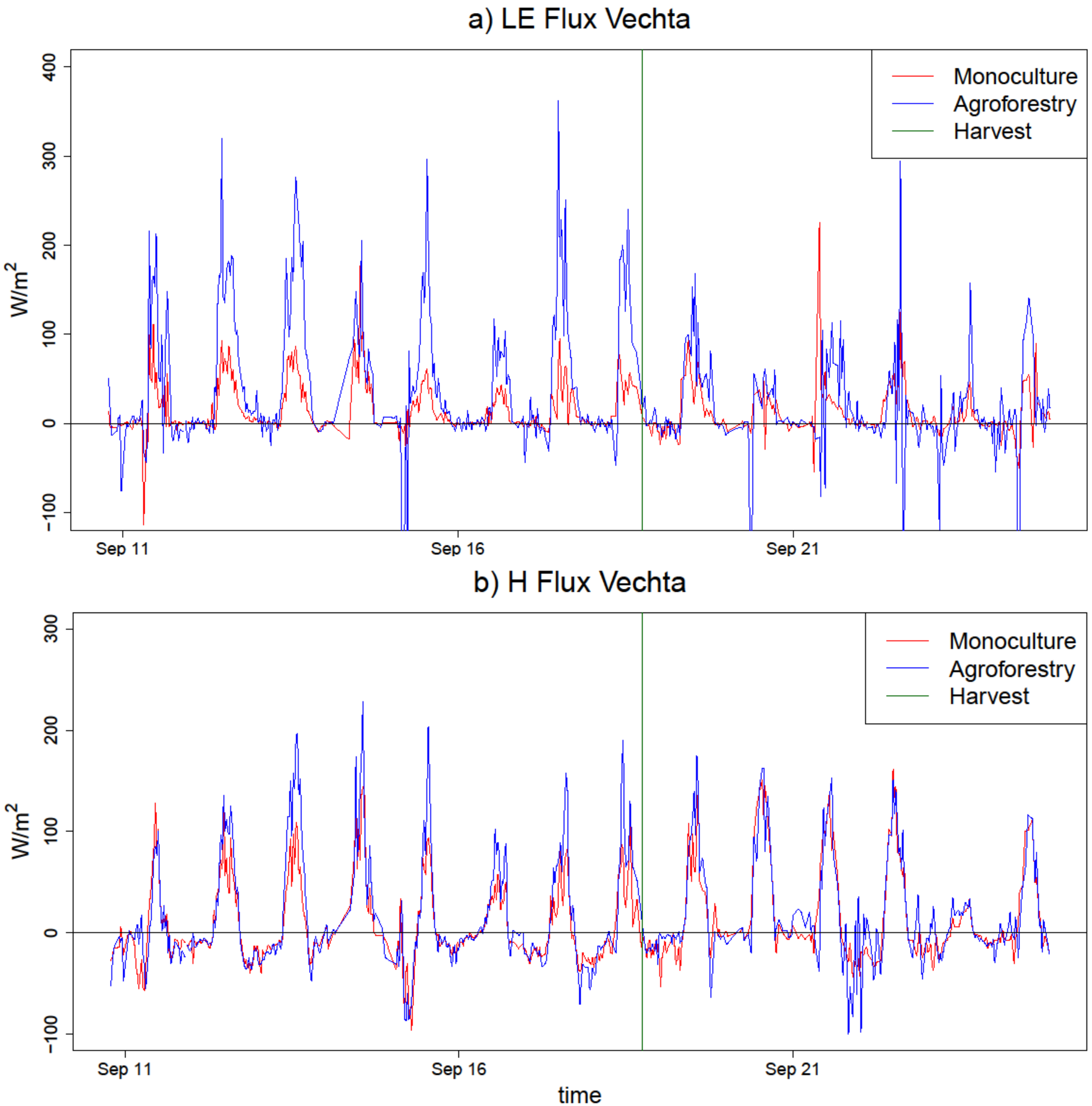

Figure 10: a) Daily latent heat flux, b) Daily sensible heat flux.

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Conclusions and future work

- The low-cost eddy covariance system is able to capture the turbulence and to measure the CO_2 flux over the agroforestry and monoculture agricultural system.

In the future we aim to:

- Improve the quality of the CO_2 fluxes, by adapting post-processing software to more precisely estimate the difference in carbon uptake between the agroforestry and monoculture systems.
- Verify the performance of the used low-cost CO_2 flux sensors.
  - We will perform a comparison at one location with two LI-COR 7200’s (this summer). One at the agroforestry site and one at the adjacent reference site.

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References

[1] Schoeneberger, M.M. Agroforestry: working trees for sequestering carbon on agricultural lands. Agroforest Syst 75, 27–37 (2009). https://doi.org/10.1007/s10457-008-9123-8

[2] Hill, T., Chocholek, M., and Clement, R.: The case for increasing the statistical power of eddy covariance ecosystem studies: why, where and how?, Glob. Change Biol., 23, 2154–2165, https://doi.org/10.1111/gcb.13547, 2017.

[3] Markwitz, C. and Siebicke, L.: Low-cost eddy covariance: a case study of evapotranspiration over agroforestry in Germany, Atmos. Meas. Tech., 12, 4677–4696, https://doi.org/10.5194/amt-12-4677-2019, 2019.

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