# Better informed decision making in consumers' food choice, breeders' crop design and protein transition
# Subproject 2 (parbars)

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# 1 Introduction

The project explored the construction and usages of the so-called parbars, cheap ceptometers sensors to measure light intercepted by the canopies. The construction of the parbars was originally described by Salter et al. (2019)[1].

## 1.1 Project activities

We can divide the activities in three WP: building the parbars, usage in the field, data analysis.

### *1.1.1 Work package 1: Building the parbars*

The original proposal aimed at building at least 4 parbars, in the context of the project several sets of parbars were built. Here we briefly describe the different sets.

#### 1.1.1.1 Set 1 - OneCue systems

The first batch of parbars were built for the project by OneCue systems. The first set consisted of 6 parbars for the project. The description of the parbars and the instruction manual produced are reported in the appendix. The technical design and the electronics of the OneCue Systems parbars (set 1 and 2, see appendix) has been designed by Arthur Rep. The major change with respect to Set 2 and the original design by Salter et al. (2019) was the use photodiodes from OSRAM SFH 2240.

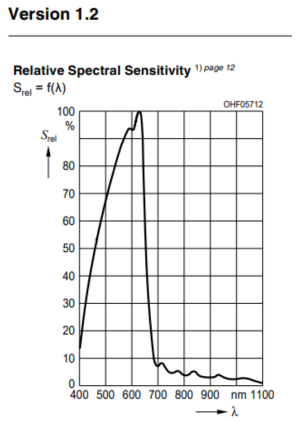


*Figure 1: Spectral response of the OSRAM SHF 2240 which is also in the range 400-700 as the original one used by Salter et al. (2019).*

#### 1.1.1.2 Set 2 - QING

The proposal of the parbars caught the attention also of NPEC —a large phenotyping facility at WUR — who before the project started ordered 6 parbars through a different company (QING). Once the project started we joined forces between this project and NPEC to calibrate the parbars and prepare a logger to record the output and store it in the NPEC servers. In the context of this project we calibrated the parbars against a reference LICOR and prepared a logger to log the signal from the six parbars, process it and store it in the NPEC servers (see Appendix).

#### 1.1.1.3 Set 2 - OneCue systems

The major difference with set 1 is that this time the photodiodes has been automatically mounted on a PCB, instead of being soldered on two wires. This is a procedure that we believe will greatly diminish the risk of errors in the building of future parbars and also the time to build them.

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[1] Salter et al. (2019) PARbars: Cheap, Easy to Build Ceptometers for Continuous Measurement of Light Interception in Plant Canopies. DOI: 10.3791/59447

#### 1.1.1.4 Parbars holders

A major source of error in using light ceptometers come from not holding the ceptometer parallel to the ground. As planned in the proposal we collaborated with Tupola (as originally conceived in the proposal) to build some parbars holder that have the following characteristics: are sturdy enough to be hammered into the ground, the position of the holder can be adjusted so that the parbars can be hold on top of the canopy or at the bottom of the canopy (depending whether the bottom of the canopy radiation or the top of the canopy radiation is required).

#### 1.1.1.5 Data logging

Data logging is also an important part of the parbars. Here we tested three different logging strategies that respond to different usage contexts.

##### Sigfox - PARBARS in a commercial field

The adoption of parbars on a larger scale, for example the adoption from farmers to facilitate crop monitoring require the adoption of a data logging system that is powered by batteries or solar power, long lasting (so that the Parbar can be installed in the field at the beginning of the season and removed at the end of the season) and remote so that the data are automatically uploaded to cloud, without the need to visit the field. The solution that we realized with together with OneCue systems was the use of Sigfox a cheap wireless networks that allows low-power objects to transmit data to the cloud. The coverage of Sigfox is excellent in the Netherlands and Europe in general and expanding in the rest of the world (Figure 2). Moreover Sigfox transmitter are already embedded in Arduino microcontrollers, so it was possible for us to connect each Parbar to an Arduino Mkrfox 1200 to log the data from the parbars onto the cloud. The data can then be pushed from the Sigfox server to a database using a back call mechanisms that transmit the new data as they become available. More details are provided in the Appendix manual.

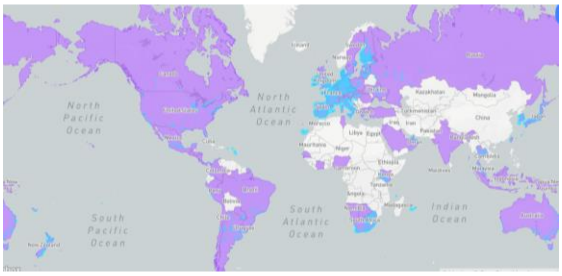


*Figure 2: Coverage of Sigfox 0G network. Light blue indicate current live coverage whereas purple indicate the areas under roll-out (source: https://www.sigfox.com/en/coverage, visited February 21st 2022).*

##### Greenhouse

In the greenhouse (in this case the NPEC greenhouse) there were no problems of powering the logger and the transmission of the data could rely on ethernet connections. In this case we focused on procuring one single logger that could retrieve the information from all the parbars at a relatively fast rate and by measuring voltage with a high precision using an integrated chip that could amplify and measure voltage with a high resolution. For this purpose we built a dedicated logger that relied on a raspberry pi to collect the data and transmit them to an external database.

## 1.2 WP 2 and 3 : testing in the field and data analysis

#### 1.2.1.1 Field testing 2021

The parbars of set 1 has been tested in a Unifarm field, where two different varieties of potato were cultivated, *Avamond* a late cultivar and *Frieslander* an early cultivar (Figure

3). One parbar was installed on top of the canopy to measure incoming radiation and the rest was used to measure the radiation at the bottom of the canopy. The parbars reproduced the expected behavior of a dying canopy (Figure 4) with intercepted radiation decreasing over time. The intercepted radiation was calculated as: (incoming-bottom)/incoming*100.

*Figure 3: Sensors in the field. On the left the parbars at the end the end of the season at the bottom of the canopy and on the right in the middle of the season at the bottom of the canopy.*

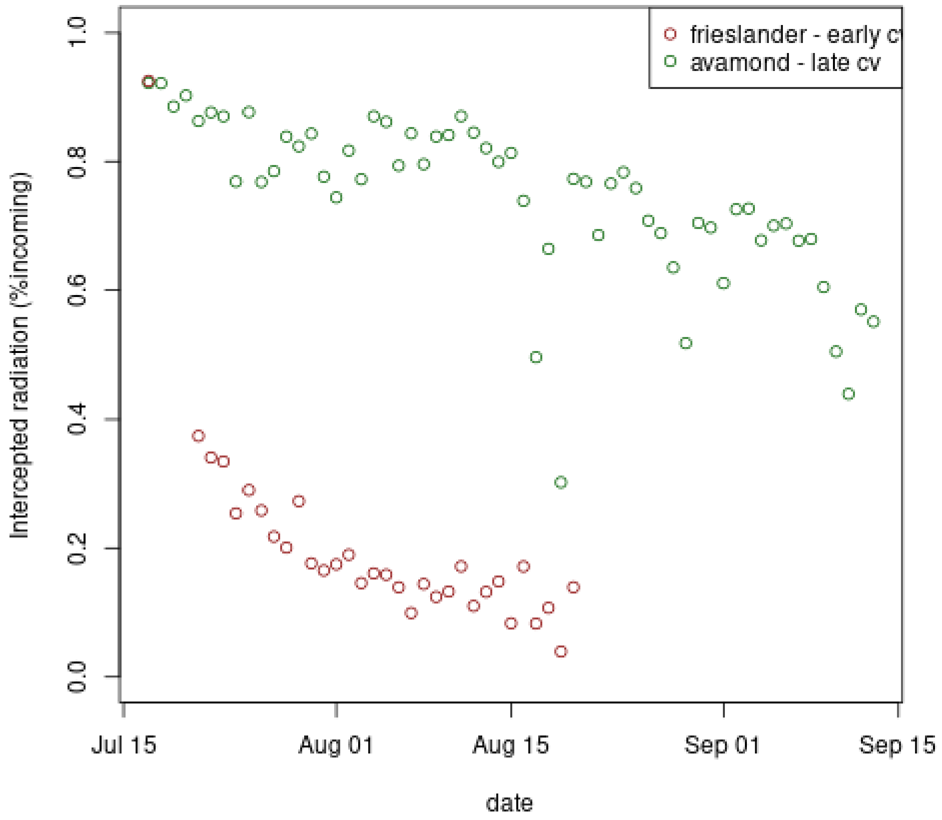


*Figure 4: Changes of intercepted radiation over the senescent part of season for two potato cultivars (Frieslander, early cultivar) and Avamond (late cultivar), intercepted radiation has been averaged by day.*

1.2.1.2 Field testing 2022

The parbars of set 2 has been tested in a potato field located in Brabant in a loamy soil with three different cultivars in 2022, and two levels of nitrogen (0 and 150), the parbars were placed soon after emergence at the beginning of June and removed toward the end of June. The field canopy reflectance was monitored over three dates in June and intercepted PAR was compared to LAI (estimated using wdvi calculated from drone multispectral images, using equation from Uenk 1992[2]) and to ground coverage (in this case plant coverage was segmented using a threshold of wdvi green > 0.4). Results indicate an agreement between intercepted radiation and canopy indicators (LAI and ground coverage coverage), however the potato growth was hampered by the drought that year so the canopy developement has been quite poor and did not reach canopy closure which caused a high variability on PAR interception by the sensors.

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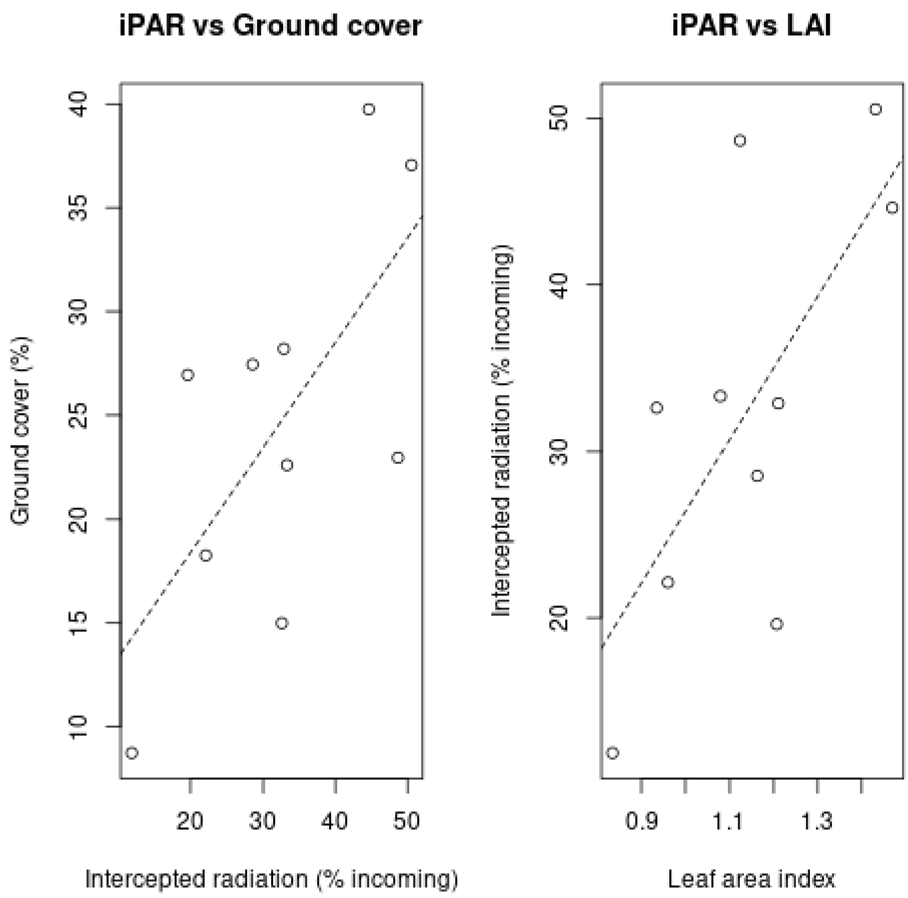
[2] https://edepot.wur.nl/331179 page 41

*Figure 5: Drone view of the parbars placed at the beginning of the season.*



# 2 Activities generated by the project

The PARBAR project generated great interest and several collaborations with different projects. The project Sunbiose a PPP on Agrivoltaic decided to use build 20 parbars to measure light interception in high value crops (e.g. strawberries) grown under solar panels. In this context we worked with Tupola and the Sunbiose project on the realization and design of PARBARs that were deployed with success in a strawberry and in a raspberry agrivoltaic systems to measure light intercepted by the solar panels and by the crops.

# 3 PARBARs calibration

The two sets of parbars were calibrated independently on two or more days.

*3.1.1 Set 1*

The first set of parbars was calibrated on the 2021-06-16 and 2021-06-11 between 11 am and 4 pm. The results of the calibration are shown in Figure 6. The regression coefficients and the fitness indicators ($r^2$) are reported in Table 1.

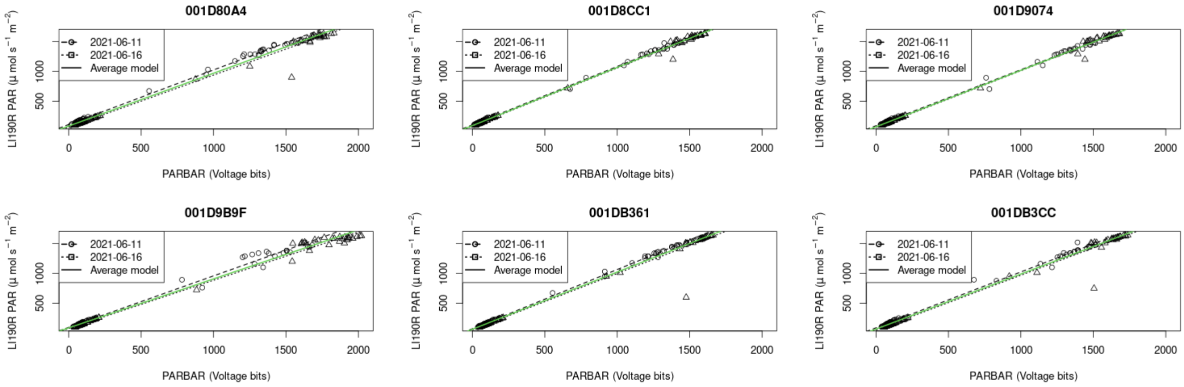



*Figure 6: Calibration of Set 1 of Q1 parbars.*

*Table 1: Regression coefficients and fitness (r squared) of the parbars from set 1. The columns are the ID (assigned based on the Sigfox module of each parbar).*

| | 001D80A4 | 001D8CC1 | 001D9074 | 001D9B9F | 001DB361 | 001DB3CC |
|---|---|---|---|---|---|---|
| (Intercept) | 88.61933 | 95.62269 | 76.07161 | 91.45539 | 68.45592 | 71.566 |
| bits | 0.882184 | 0.972677 | 0.943636 | 0.818745 | 0.955779 | 0.920008 |
| r squared | 0.989313 | 0.997612 | 0.996981 | 0.989813 | 0.9825 | 0.986561 |

## 3.2 Set 2

The second set of PARBARs was built and calibrated in June 2022 over 3 dates, the results are shown in Figure 7 and the coefficients of the regressions are in Table 2.

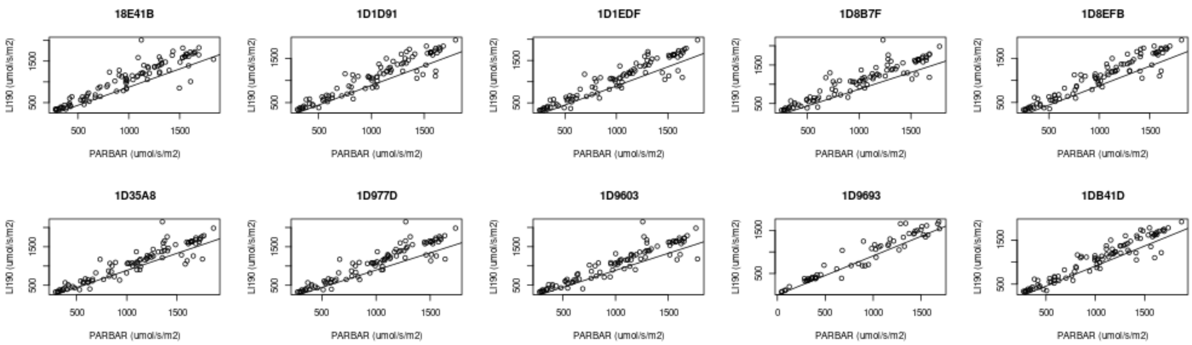



*Figure 7: Calibration of the second set of PARBARs.*

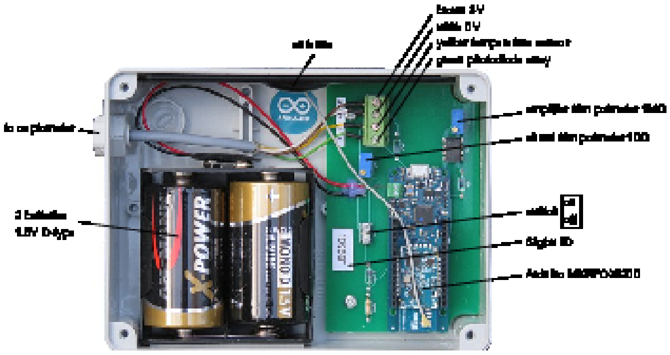
*Table 2: Coefficients and r squared of the devices tested in the second set.*

| | 18E41B | 1D1D91 | 1D1EDF | 1D8B7F | 1D8EFB | 1D35A8 | 1D977D | 1D9603 | 1D9693 | 1DB41D |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | 146.72 | 95.49 | 166.7 | 110.85 | 114.09 | 107.41 | 71.27 | 112.4 | 123.01 | 147.15 |
| bits | 0.79 | 0.84 | 0.79 | 0.81 | 0.82 | 0.81 | 0.87 | 0.82 | 0.82 | 0.81 |
| r squared | 0.75 | 0.75 | 0.65 | 0.77 | 0.78 | 0.75 | 0.76 | 0.75 | 0.69 | 0.71 |

# 4 Appendix

# Ceptometer Sigfox module

The Module is developed by One Cue Systems for long term use in the field to monitor the light intensity over and between the canopy of crops under experimental conditions. Each module consists of a ceptometer containing 43 photodiodes each and a temperature sensor, attached to an enclosure containing and Arduino MKRFOX1200 module that transmits every 15 minutes averaged, coded data of 5 minute periods to the Sigfox backend. By accessing the backend the data can be retrieved and decoded in Excel.



### Operation

The module is controlled by a micro-controller. The firmware collects every 5 seconds a reading from the ceptometer and computes the average over 5 minute periods. After three periods (15 minutes) the three averages are sent to the Sigfox Backend, together with the values of the battery voltage and the temperature in °C.
The decimal values are converted into hexadecimal values in order to minimize the payload.

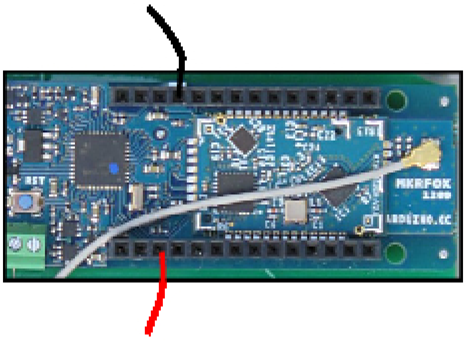
After switching on the module, the actual values are transmitted in 5 seconds. This is intended for calibration of the module.

### First time start-up

- Place the ceptometer in horizontal position in a place to which unauthorized persons have no access.
- Check the correct wiring to the green terminal block.
  Brown: 3V
  White: 0V
  Yellow: T
  Green: L
- Activate the module by switching the power to the on position.
- Wait for 5 seconds and check if the data is received by the Sigfox Backend, using the right Device ID.
- Close the box with a bag of silica gel and tighten the lid with the 4 screws (not too tight!) and put it on the ground with the antenna on top.

### Calibration

The module can be calibrated using a professional lux meter or LI-COR quantum sensor. The blue 10Ω potentiometer next to the green terminal block determines the shunt resistor value over the photo diode array. The higher the resistance, the higher the output voltage of the ceptometer, but at the expense of linearity. The other 1MΩ potentiometer next to the black 8-pin opamp determines the amplification or gain factor. Upon delivery the values are approx. 5 Ohms and 100 kOhms giving a 10 fold gain. The resistance of the shunt can be measured over the terminals 0V and L after disconnecting the green wire. By adjusting the screw on the gain potentiometer, the gain can be set up to 100-fold, with an output that corresponds to the lux or LI-COR value. A high gain factor may result in an offset value >0 in the dark.



The output voltage of the amplifier can be measured using a multimeter over A1 and GND - see the picture above. A voltage of 1000 mV will send a value of 4095 to the backend, so a voltage of 400 mV corresponds to a message value of 400/1000 x 4095 = 1638.

By running the program calibration.ino the values that are sent to the backend are shown on your computer screen.

### Conversion of the data

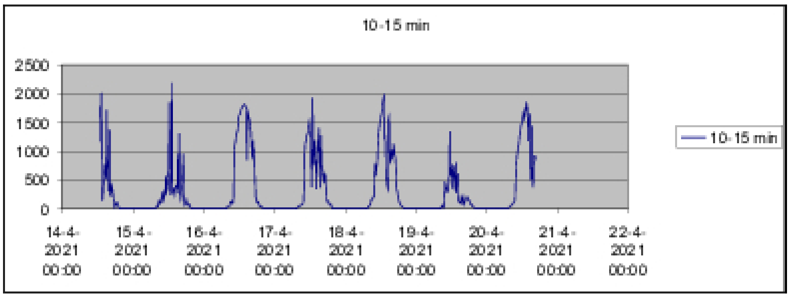
Sigfox demands the data to be converted into hexadecimal format. The above value of 4095 becomes 0FFF, 1638 becomes 0666. A typical string arriving at the backend could be aa013001a5064c0632061e, meaning
aa dummy to make each string contain some characters, to make it a text string,
0130 hex for 304, divided by 100 gives the battery voltage 3,04 volts,
01a5 hex for 421, divided by 10 minus 20 gives the temperature 22,1 °C,
064c hex for 1612 the value for light intensity of the parbar during the first 5 minutes,
0632 hex for 1586, the light intensity during the following 5-10 minutes,
061e hex for 1566, the light intensity during the last 10-15 minutes before transmission of the data.
30 is sent as char(30) = "0", 4c is sent as char(4c) = "L", to be looked up in an ASCII table.

Using a macro in Excel the decoding is performed in an instance.

### Retrieving and decoding data from the backend

If you want to retrieve the data from the backend you have to sign in with your user ID (your e-mail address) and your password. Then choose the DEVICE tab, select a device by clicking on the ID of the device, and finally on MESSAGES in the panel to the left.


By clicking CSV you can export the last page of 100 data immediately or all the data, for which you will become an e-mail. The attributes to export are Data, Link Quality Indicator and Timestamp. Double clicking the export_device_ID icon the data are loaded into Excel. After removing the first line the data can be selected with CTRL+A, copied with CTRL+C and pasted into hex-to-dec-V2. Decoding occurs by pressing SHIFT+CTRL+C. The data are now decoded in decimal format and available for further analysis.




## Specifications

| | |
|---|---|
| Ceptometer: | |
| Photo diode array: | 43 Osram SFH2240 visible light sensors, parallel. |
| Dimensions: | 820mm x 25mm x 15mm. The first photo diode at 50 mm from the cable outlet, the last photo diode at 20 mm from the end. |

| | |
|---|---|
| Transmission module: | |
| Power supply: | 3 Volt, two D-type batteries of 1.5 Volt each. |
| Power consumption: | ca. 1 mA. |
| Temperature: | -10 to 45 °C. |
| Dimensions: | 150mm x 110mm x 70mm. |

## Terminals

| | |
|---|---|
| 3V 0V T L | Connection for the ceptometer.<br>The 3V terminal is power supply for the temperature sensor (Dallas 18B20).<br>The 0V terminal is the common ground.<br>The T-terminal receives the data from the teperature sensor.<br>The L-terminal connects to the photo diode array.<br>Note proper connection! |

# 6 NPEC PARBARs calibration and data logging

Project: NWA-route 2020 ‘Better informed decision making in consumers' food choice, breeders' crop design and protein transition’

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# 7 Calibration

The voltage generated by the PARBARs have been calibrated against a LI-190R available at Unifarm (unique identifier 018272). The PARBARs were parallel to ground in an open field placed under the direct sun. A linear regression voltage ~ $PAR_{LI190R}$ was fit separately for each PARBAR. The calibration was performed on two days (31/3/2021, 21/4/2021) to ensure the repeatability of the calibration over time. The LI190R was set to record one value every 10 minutes, whereas the PARBAR to record one value approximately every 17 seconds (averaged over 0.5 seconds measurements interval). The PARBAR values were then averaged over the 10 minutes periods and regressed against the 10 minutes average LI190R PAR.

The PARBARS showed a good linearity with PAR in the range 800-1600 umol/s/m2 (Figure 8,Figure 9). On the April calibration date the correlation is less strong probably because that was a very cloudy day and with highly variable light conditions, with the current setup each sensor logs an instantaneous recording every 15 seconds, so it is possible that sudden light changes introduce noise in the measurements. The reference light meter (LI160) was set to log the average every 10 minutes (by pooling together measurements that were recorded 1 second apart).

The regression curve between the two dates showed a good agreement (Figure 10), except for PARBAR #3 where a discrepancy in the slope was observed. We believe that this may be due to a movement of the PARBAR during the day because of the wind that moved the PARBAR from its levelled position.

Therefore, since only 5 PARBARs were planned to be used in the NPEC facility we suggest to use PARBAR #1,2,4,5,6 . The coefficients of the linear regressions are given in Table 3.

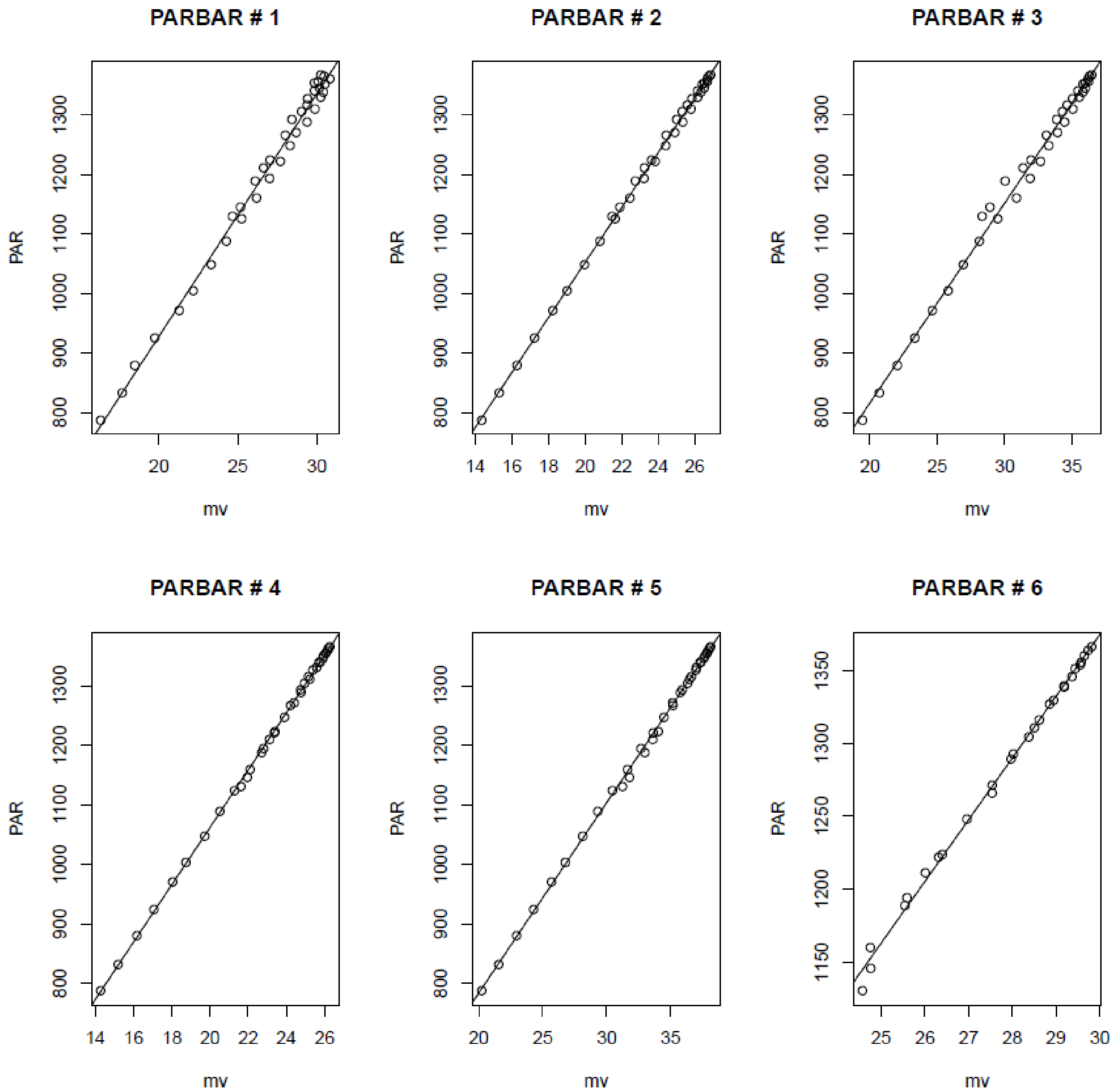


*Figure 8: Regression PAR~voltage from data measured on March 31st for each PARBAR. PAR is measured as umol/s/m², voltage is in mv.*

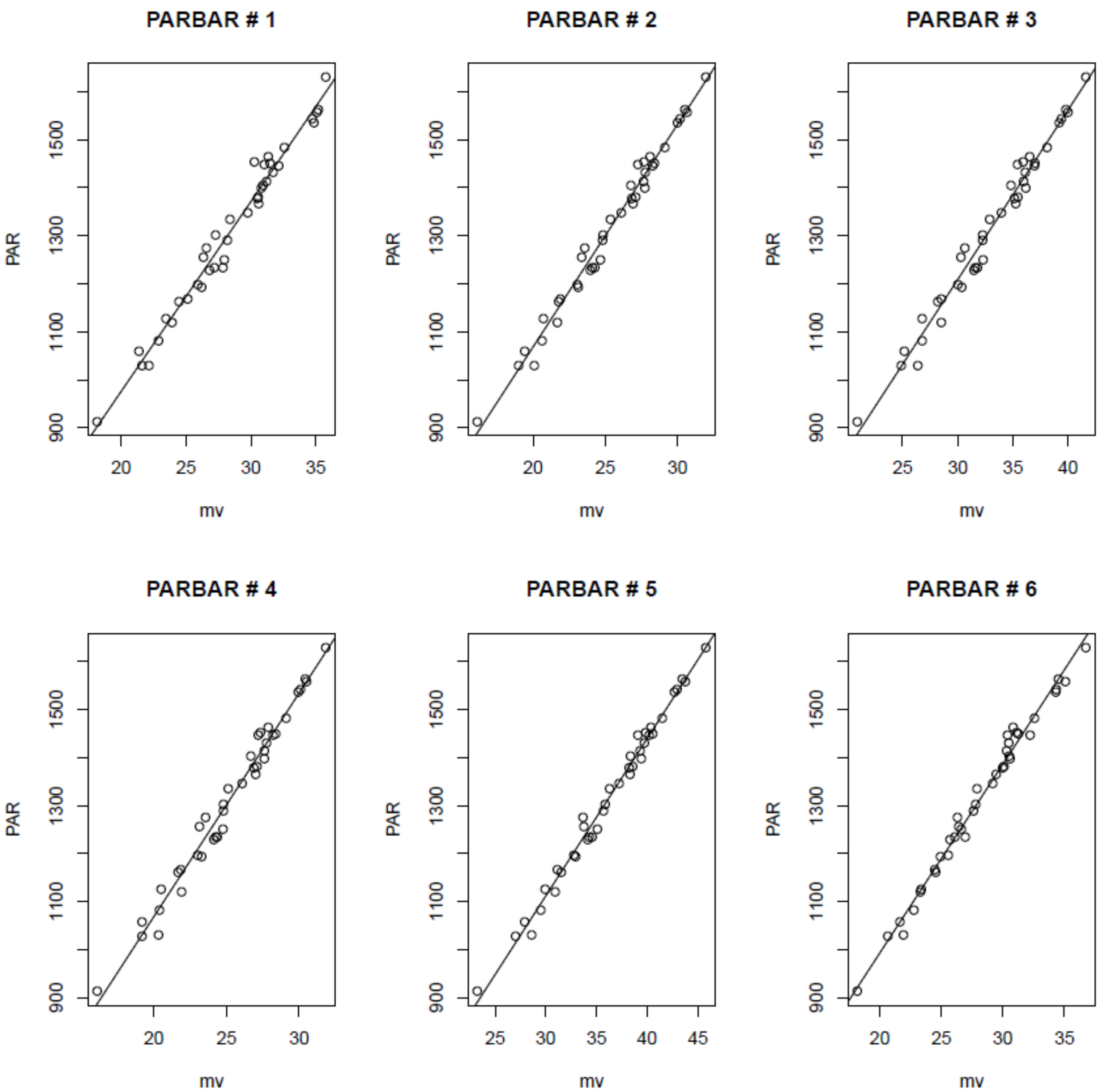


*Figure 9: Figure 1: Regression PAR~voltage from data measured on April 21st for each PARBAR. PAR is measured as umol/s/m$^2$, voltage is in mv.*

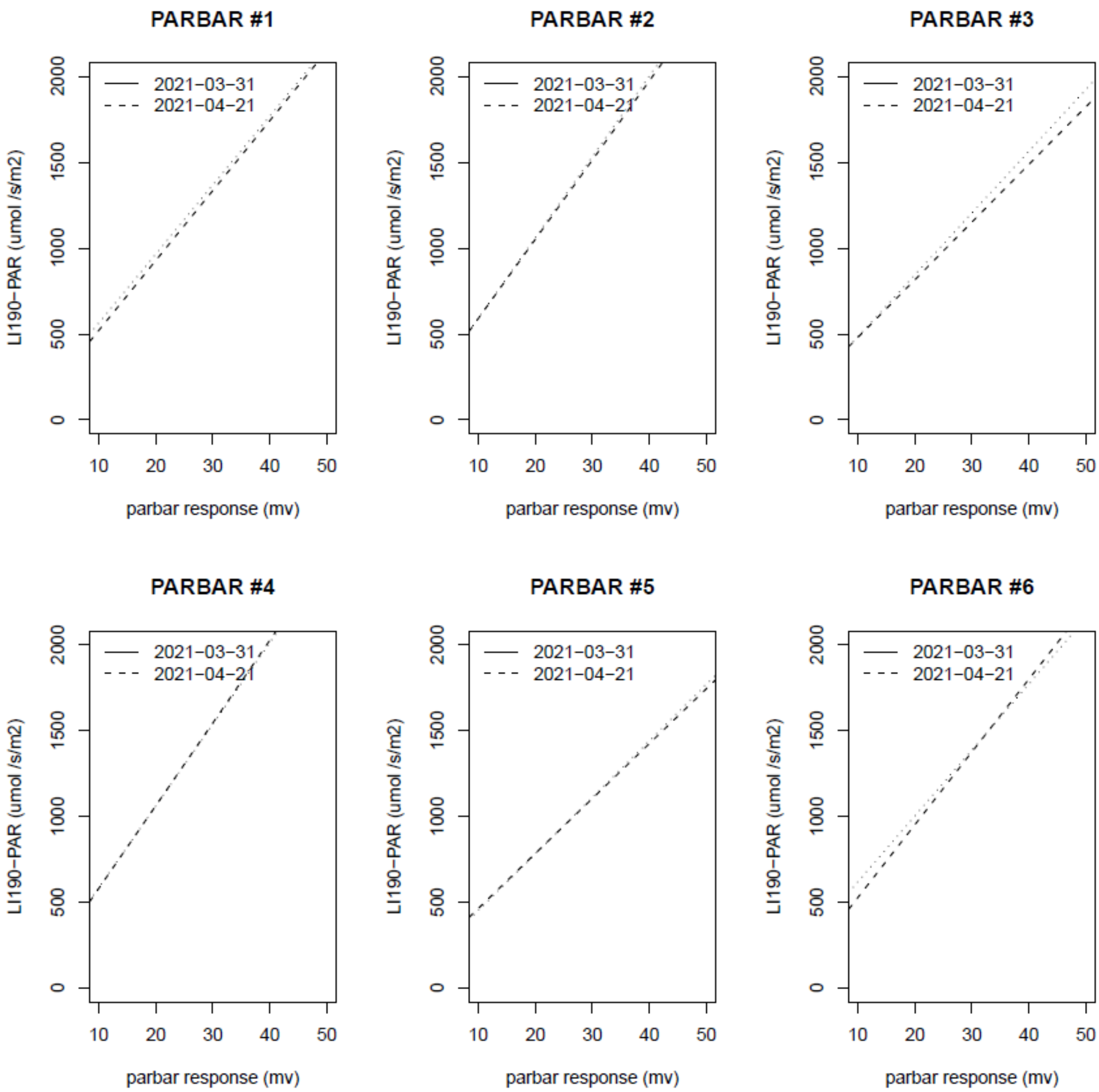


*Figure 10: Comparison of the calibration curves on the 2 calibration dates.*

*Table 3: Regression coefficients for the PARBARs in the two calibration dates and their average.*

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **03/31/2021** | | | | | | |
| **INTERCEPT** | 113.6 | 128.8 | 143.8 | 98.2 | 144 | 103 |
| **SLOPE** | 40.7 | 46.1 | 33.6 | 48.2 | 32 | 42.4 |
| **04/21/2021** | | | | | | |
| **INTERCEPT** | 185.3 | 140.7 | 147.6 | 135.7 | 128.7 | 205.8 |
| **SLOPE** | 39.5 | 46.4 | 35.4 | 46.6 | 32.8 | 39.4 |
| **AVERAGE** | | | | | | |
| **INTERCEPT** | 149.5 | 134.8 | 145.7 | 117 | 136.3 | 154.4 |
| **SLOPE** | 40.1 | 46.3 | 34.5 | 47.4 | 32.4 | 40.9 |

# 8 Data logging and storage

The voltage output from the PARBAR (which contained a 1.5 omh resistor in parallel, as suggested in the original publication) was amplified 16 times and converted into a digits using a 16 bits analog to digital converter (ADS 1115, Texas Instruments) which has an integrated programmable amplifier. The nominal resolution of the analog to digital converter is 7 microV. The data from converter are recovered, transmitted and stored using a raspberry pi 4. The logger is hosted in a IP66 case (protected against dust and direct water jet).
Each PARBAR recorded 1 value every 2 seconds, then 5 measurements were averaged and stored in an external database. Including the time required to upload the recordings on the database, the result was on average one recording every 17 seconds. On 10% of cases there was one recording every 20 seconds and in 10% of the cases it was a recording every >24 seconds, with a maximum of 81 seconds. The recording time was the time of the measurement not the time of the upload, so in the cases of delay the times recorded reflect the effective time of measurement. The setup was tested both in the field where we used a mobile connection and in the greenhouse where it was tested using an ethernet cable.
The script to record and measure the data was written in python. The measured data are then uploaded using pandas and sqlalchemy on a Postgres database.

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