

# Environmental parameters on the carbon balance of the Wadden Sea salt marshes at Lutjewad from May to June

Bachelor Thesis, Applied Physics  
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## Abstract

The carbon exchange of the Wadden Sea Salt marsh near the Lutjewad Weather station is investigated during a period of 7 weeks. Three vegetation species are studied: *Elymus Athericus*, *Festuca Rubra* and *Spartina Townsendii*. The average carbon sequestration for the 25<sup>th</sup> and the 26<sup>th</sup> of May is estimated on  $14 \mu\text{mol m}^{-2} \text{s}^{-1}$  for *Elymus Athericus* and on  $4 \mu\text{mol m}^{-2} \text{s}^{-1}$  for all species. This high difference is caused because the value of  $14 \mu\text{mol m}^{-2} \text{s}^{-1}$  is measured on one position, where the circumstances were optimal. *Elymus* and *Festuca* have corresponding GPP. However, the respiration rate for *Festuca Rubra* is lower. *Spartina* was only just starting its growing season, so the GPP was much lower than that of the other two species. Besides solar irradiance, temperature is found to be a significant factor for the total gross primary production (GPP). Tidal factors may also influence GPP. Higher biomass seems to correspond to higher respiration rate, although the data was obscured by scatter. Our measurements with the closed chamber technique agreed closely with nearby eddy-correlation data.

## 1. Introduction

Increased anthropogenic carbon dioxide emissions are a major cause of the temperature increase of the atmosphere. The temperature has been rising with  $0.16^{\circ}\text{C}$  per decade during the last 50 years. The temperature is expected to increase with a value between  $1.1^{\circ}\text{C}$  and  $6.4^{\circ}\text{C}$  this century. (Parry, et al., 2007). Among other things, this leads to sea level rise -which will cause floods in coastal zones with low elevation- more droughts in Mediterranean countries and regions around the equator, and expansion of tropical diseases to temperate climate regions (Parry, et al., 2007). To mitigate these effects  $\text{CO}_2$  emissions should be reduced. On the other hand, ecosystems are able to sequester  $\text{CO}_2$  in biomass, which results in lower  $\text{CO}_2$  concentration in the atmosphere.

One of these types of ecosystems are salt marshes. Salt marshes are found at the boundary between sea and land at places where the coast is protected from destructive waves, usually in middle and high latitudes (Mitsch & Gosselink, 2000). The total area of salt marshes in the world is around  $22.000\text{ km}^2$  and the total area of wetlands (tidal salt marshes and mangrove Swamps) at least  $200.000\text{ km}^2$ . The average sequestration of these wetlands is  $210\text{ g C m}^{-2}\text{ yr}^{-1}$  for both mangroves and salt marshes. This contributes to a carbon sequestration of  $4.62\text{ Tg C yr}^{-1}$  for salt marshes and  $44.6\text{ Tg C yr}^{-1}$  for all wetlands (Chmura, et al., 2003). This high sequestration is due to a high primary productivity of vegetation and the fact that over 90% of the carbon fixed by photosynthesis is sent in the ground for root production (Ryan & Law, 2005). The crucial property that gives the salt marshes the high net productivity is that the sediments will not become saturated, which is due to the accumulation of sediments (Mitsch & Gosselink, 2000).

Practically the entire northern coast of the Netherlands and Germany and the east coast of Denmark, the Wadden Sea coast, consists of salt marshes. However, there has been barely any research done on the  $\text{CO}_2$  sequestration of these salt marshes. Although salt marshes are assumed to have the same ecological structure all around the world, (Mitsch & Gosselink, 2000) the Wadden Sea salt marshes may differ from other marshes because they are much younger; The salt marshes at Lutfjewad started *growing* after the last dike construction around the previous salt marsh in 1923 (Slabbers, 2004). By contrast, the marshes at the Northeast coast of the United States are 4000 to 7000 years old (Hartig, et al., 2002). So it could be that the Dutch marshes have not yet reached an equilibrium of carbon sequestration-emission that the US salt marshes might have reached. This might result in a different carbon sequestration. Also the local rate of sea level rise might affect the sequestration rate of the salt marshes because a higher sea level rise causes more inundations of the salt marsh, which will result in a faster accumulation of sediments and more capacity for carbon sequestration. Of course, environmental parameters like solar irradiance and rainfall influence the carbon sequestration too. This research project aims to determine the carbon balance of the Dutch salt marshes.

The Dutch salt marshes grow at an average rate of 1-2 cm a year in height (Bakker, et al., 1993) still relying on an average carbon sequestration of  $210\text{ g CO}_2\text{ yr}^{-1}$  and no loss of carbon to the sea, the average carbon concentration in the soil should be  $0.011\text{--}0.021\text{ g cm}^{-3}$ . The average carbon concentration in the soil of salt marshes worldwide is  $0.04\text{ g cm}^{-3}$  (Chmura, et al., 2003). So from this point of view there's no reason to say that a lot of carbon will flow from the salt marsh into the sea. This makes the salt marshes even more interesting as a carbon sink because carbon flowed away into the sea will end up in the atmosphere. This calculation suggests that the salt marsh can really sequester carbon in its soil for long times.

Another reason why it is interesting to do this research now, is that starting in May there will be major adjustments done to the marshes near Lutjewad by the *kwelderherstel* organization. The goal of their project is to get greater biodiversity in the marsh and make it a recreation area. Therefore they let sheep graze to restrain the fast-growing high grasses. They expect that rare plants will start growing on the bare soil. To make the marshes suitable for the sheep to graze, ditches have to be dug out or damped so sheep can't get stuck and drown in these ditches. Refuge areas will be built for the sheep as shelter for during inundations of the tidal flat. For hikers paths and a viewpoint will be made (Kwelderherstel, 2009). All these adjustments will have impact on the total carbon balance of the marsh; the aim is to find out what the effects of these excavations are; in a subsequent research project the long-term consequences might be investigated.

We also want to know more about the carbon flux of the salt marsh because the Lutjewad research tower is very close to the salt marsh. It is not known sufficiently what part of the carbon flux measured in the tower during northern wind is caused by the salt marsh. Wim Klaassen estimated the share of the salt marsh in the total flux measured at 80 %, but if this percentage is known more precise, the tower measurements can be analyzed more accurately.

So the general aims of this research project are:

- Finding what the influence of environmental parameters is on the carbon balance of the Wadden Sea salt marshes at Lutjewad, from May to June
- Finding out what the effects of the excavation on the CO<sub>2</sub> balance in the salt marsh are.

The Wageningen University will execute eddy covariance measurements on the salt marsh to measure the total carbon balance of these. However, this method does not inform on spatial variability. Spatial variability can be determined using Closed Chamber technique.

Many parameters may affect the CO<sub>2</sub> flux of the vegetation in the salt marsh. The most important are: the amount of solar radiation and temperature of the leaves of the plants. Other factors are the size of the plants and the salinity of the ground, where high salinity has negative effects (Fagherazzi, et al., 2012). Also elevation, which influences the groundwater depth, and tidal regime influence the growth (Silvertri, et al., 2004). At higher solar irradiance, phosphorus and nitrogen concentrations in the soil can be limiting to the photosynthesis rate; Van Wijnen and Bakker found out that nitrogen limitations occur in 100 year old Marshes at Schiermonnikoog (Wijnen & Bakker, 1999).

For this research project only the most influencing parameters (light flux and temperature) are taken into consideration. Also the amount of biomass is measured because besides the fact that on a larger leaf area there can be more photosynthesis, biomass is, for annual plants, a measure for growth in recent time, so larger annual plants are expected to grow faster.

## **2. Research design and questions**

The following parameters are considered in particular:

1. CO<sub>2</sub> flux, both respiration flux and net flux, for the most common vegetation species; *Elymus Athericus*, *Spartina townsendii* and *Festuca Rubra*
2. CO<sub>2</sub> flux of bare soil for regions where used to be *Elymus Athericus*, *Spartina townsendii* and *Festuca Rubra*.
3. CO<sub>2</sub> flux from the bottom of tidal ditches.
4. The effects of solar radiation on CO<sub>2</sub> flux
5. The effects of temperature on CO<sub>2</sub> flux
6. The effects of biomass on CO<sub>2</sub> flux

Measurements will be done using closed chamber technique. The closed chamber technique might be prone to errors, to estimate these errors; the data will be compared to data from Wageningen University. Wageningen University will do Eddy Covariance measurements and measure spatial variability of the soil respiration. It will be interesting to compare our results to determine systematic errors of the measurement methods.

## **3. Measurement technique**

There are different methods to measure carbon dioxide flux: Eddy Covariance technique, closed chamber techniques and flow-through- or open chamber techniques. The Eddy Covariance technique is a measurement technique which estimates CO<sub>2</sub> flux from the covariance between vertical wind speed and the CO<sub>2</sub> concentration at a certain height above the surface in a mast (LI-COR Biosciences, sd). The advantages of this measurement method are that continuous measurements can be done, the surface is not disturbed by the measurements, and measurements are integrated over a large area. The integration is also a disadvantage, because spatial variability and influences of different types of vegetation, which might be interesting, are ignored. Also variations in weather conditions may influence results. Besides that, this measurement method is relatively expensive.

Chamber techniques make use of a chamber placed on or pushed into the soil of a certain type of vegetation. So, the source of the flux is well defined within the chamber and this makes the chamber techniques especially suited to measure spatial variability and influences of variation in the vegetation. Chamber techniques are much cheaper than Eddy Covariance technique. However, since chambers are pushed into the soil stems are damaged, which might influence results, also temperature and humidity in the chamber may vary during measurements which causes errors in the measurements.

In a flow-through chamber, the air is refreshed continuously with outside air, which means that long measurements are possible, since the CO<sub>2</sub> concentration stays at a more or less constant level. The flux is calculated from the difference in concentrations between the air flowing at a known rate through the inlet and outlet of the chamber, after the chamber headspace concentration has reached equilibrium (Pumpanen, 2011). In closed chamber technique the air inside the chamber is isolated. For mixing of the air inside the chamber a ventilator is used and a CO<sub>2</sub> analyzer measures the CO<sub>2</sub> concentration in the chamber. Because the air in the chamber is isolated it is easy to find the

CO<sub>2</sub> sequestration by the plants. With this technique only short measurements can be done, since the CO<sub>2</sub> concentration has influence on the CO<sub>2</sub> sequestration of the vegetation.

A disadvantage of closed chamber techniques is that it is hard to avoid mixing of the air inside the chamber with outside air, because it is hard to push the base far enough in the ground to make an air-tight connection. When the air in the chamber is hermetically sealed from the outside air successfully, there is a risk that pressure differences occur, which have large influence on the soil respiration (Davidson, et al., 2002). That's the reason why the most closed chambers are equipped with a valve to avoid these pressure differences. Despite the differences between the two techniques, both chamber techniques give approximately the same results (Burrows, et al., 2005).

The measurement method I used is closed chamber technique, where the CO<sub>2</sub> concentrations are measured with a Vaisala Carbocap CO<sub>2</sub> open path analyzer.

### **Chamber specifications**

For the CO<sub>2</sub> measurements I use the closed chamber measurement technique. The closed chamber consists of two parts; a large and a small chamber. Both chambers are made of UV- and visible-light transparent Perspex of 0.5cm thick. The large chamber (open bottom and open top) has an area of 28x28cm and a height of 70cm. On top of this the smaller chamber is placed (open bottom closed top) size 28x28cm height 15 cm. The air in the chambers is mixed using a 12V ventilator. The chamber is placed on a metal base which is pushed into the ground. In the smaller chamber the Vaisala CO<sub>2</sub> measurer is located. In the ideal case the measurement setup is air-tight but there might be some leakage so a measurement will be done to estimate possible leakage.



*Figure 1. The closed chamber measurement setup.*

### **Vaisala**

CO<sub>2</sub> concentrations in the chamber are measured using The open path Vaisala Carbocap GMP343. The instrument makes use of an infrared sensor which measures the absorption of the infrared light by CO<sub>2</sub> molecules. The sensor is placed behind a silicon-based Fabry-Perot Interferometer which is tuned so that its measurement wavelength is switched between the absorption band and a reference wavelength. From the ratio of the two signals the CO<sub>2</sub> concentration is calculated (Vaisala, 2011).

During test measurements it became clear that there is a delay between the environmental carbon concentration and the value measured by the Vaisala: this is in particular caused by the filter of the Vaisala. The delay can be up to 80 seconds, when using averaging of 10 seconds (Vaisala, 2011).

Fortunately, we expect a linear gradient of the CO<sub>2</sub> concentration in all measurements, so the delay should not affect the results when the measurements are started 1 minute after the Vaisala being placed in the chamber.

The Vaisala Carbocap is calibrated again for pressure and temperature and CO<sub>2</sub> concentration by . The calibrations are done in a temperature range from 1 °C to 31 °C and a pressure ranging from 700 and 1050 hPa. This is done because the previous calibration might be off and the last calibration was only done for CO<sub>2</sub> concentration. The temperature for which the Vaisala is calibrated is the temperature which is measured by the Vaisala itself; this temperature has a large deviation from the air temperature outside the Vaisala. The final calibration curve is as follows:

$$[CO_2] = [CO_2]_m \cdot \frac{1}{1 + 0.00114(P - 1013)} \cdot \frac{1}{1 + 0.0010431(T - 25)} \cdot 0.93625702 \quad (1)$$

Where  $[CO_2]_m$  is the CO<sub>2</sub> concentration measured by the Vaisala, P is pressure in hPa in the chamber and T in °C is the temperature indicated by the Vaisala.

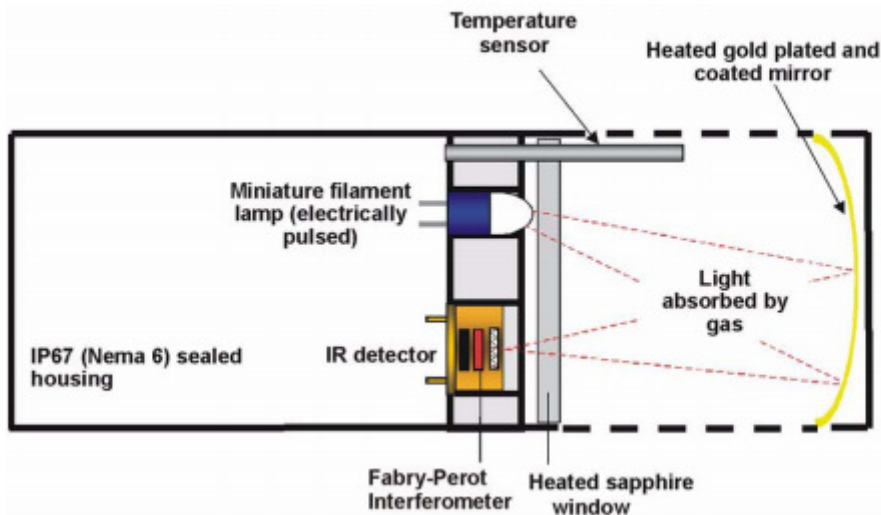


Figure 2. A schematic representation of the Vaisala Carbocap

### Measurement Location

The measurements are done on the Waddensea salt marsh near the Lutjewad Research station of the Rijksuniversiteit Groningen in Hornhuizen (figure 3) within the range of the Wageningen Eddy Covariance measurement tower; this is the higher part of the salt marsh with dense vegetation. The Lutjewad salt marsh was formed after the last expansion of the dikes to the border of the old salt marsh and the Waddensea in 1924. The formation was stimulated by digging ditches for the drainage of the marsh. Islands in the Wadden Sea protect the shore of the main land from waves, so the marsh could grow undisturbed. The salt marsh has a reasonably uniform elevation of 1 meter above sea level (Waterschapshuis, 2012).



Figure 3. Location of the Lutjewad Research station of the Rijksuniversiteit Groningen

The main vegetation species are *Elymus Athericus*, *Festuca Rubra* and *Spartina Townsendii* (figures 4 & 5). *Elymus Athericus* is the most common vegetation and covers 70-80% of the Lutjewad salt marsh. *Elymus* is a longer perennial grass up to 1 meter height. *Festuca Rubra* is also perennial, the vegetation is relatively low and dense, and grows upon a turf layer formed in previous years. *Spartina* is more reed-like grass and much stiffer than the other two. It is an annual grass (Heukels & Oostroom, sd), so it is expected that the biomass of samples of this grass is an important factor for the CO<sub>2</sub> flux. This species started growing late in the season near the end of the month May. Before this date the above ground biomass existed of dead stems of previous years. So only a few measurements are done on this grass. *Spartina* covers approximately 20% of the area.



Figure 4. *Elymus Athercus* (L) and *Spartina Townsendii* (R) on 11 april 2012



Figure 5. *Festuca Rubra* (Farm, sd)

#### 4. Measurement method

Three types of measurements were executed on the vegetation: measurements during daylight, darkness measurements to determine the share of the darkness reaction, or respiration, in the total CO<sub>2</sub> flux, and soil respiration measurements. The darkness reaction or respiration depends mainly on the temperature (Lloyd & Taylor, 1994) while the photosynthesis depends mainly on light intensity.

A standard measurement goes as follows: the Vaisala is turned on and the atmospheric pressure and humidity are set a few minutes before the first measurement, since the instrument takes a few minutes to adjust to the new circumstances. A representative part of the vegetation is chosen. At that place the metal foot is pushed into the ground. The main chamber is placed on top of the foot. It takes 1-2 minutes to let the vegetation stabilize again (Streever, et al., 1998) after that, the smaller chamber with the Vaisala is placed on top and one minute later the measurement is started. Usually 15 seconds interval and a total measuring time of 5 minutes is used.

In case of the darkness measurements the main chamber is darkened with a black cover, and the smaller chamber is replaced by an opaque one. All other steps are the same for this measurement.

When the soil respiration is measured, first the grass is removed by cutting it as close to the ground as possible. Then the metal base is placed. The problem is that the metal base disturbs the soil ecosystem. To estimate this effect I do measurements directly after the base is put into the ground and about one hour later. One base is kept in the ground to measure the soil respiration after a week. The temperature of the soil in the chamber at 3 cm depth is determined by a puncture thermometer during the flux observation period. The cut vegetation is stored and dried for 48 hours at 70°C.

Special measurements will be done during two consecutive days, to determine the effects of solar radiation and temperature on the total carbon flux of the vegetation. To exclude spatial factors, the same spot will be measured for a whole day. During these days light and darkness measurements will be done.

Measurements on May 25 and 26 started early in the morning at sunrise on a plot of *Elymus Athericus*. The temperature in the chamber is measured with an external thermometer, because the thermometer in the Vaisala is irrelevant for the chamber temperature. In the early morning the temperature won't increase very much, while the light intensity increases rapidly. In the afternoon the light intensity will be approximately constant and temperature will fluctuate more. In the evening there will be the same light intensity as in the morning, but with a different temperature. Extra temperature fluctuations can be provided by keeping the chamber on the grass for a longer time. A disadvantage of increasing temperature in this way is that the humidity increases too, which influences the CO<sub>2</sub> flux. It has been tried to dry the air with silica gel, but even then condense was formed on the chamber walls.

Darkness measurements have also been done every half hour, during these two days, to calculate the effects of temperature on the darkness reaction (Gillooly, et al., 2001).

The measurement data; CO<sub>2</sub> concentration over time, Vaisala temperature, temperature inside the chamber and biomass is linked to the *meteorological data*; air pressure at a height of 7 meters and light flux, measured at the Lutjewad Research Tower located at approximately 300 meters from the measurement locations.

### **Respiration of ditches**

Tidal ditches cover a significant part of the total area of the salt marsh (approximately 5%). To find the CO<sub>2</sub> flux of these ditches, the flux is measured by pushing the measurement setup in the bottom of the ditch during low tide (then the water in the ditches is almost gone so measurements can be done). Then the measurement is executed as usual.

Two types of ditches are measured: ditches in the tidal area where the soil was still very wet and a dried up ditch in the higher area of the salt marsh. The measurements are done in both ditches on 3 different places.

## Effects of Excavation of the soil

There was no possibility to measure the effects of the excavation of the soil, because the planned work on the salt marshes was delayed in the area I was measuring.

### 5. Data analysis method

The raw data for each light reaction measurement is analyzed using the Wolfram Mathematica program (appendix 1). In that file the  $\text{CO}_2$  concentration for every measurement has been plotted as function of time. These plots never were a perfect straight line: for the light measurements, the slope of the points decreased as  $\text{CO}_2$  concentration decreased. This is mainly because the net rate of photosynthesis is, for normal  $\text{CO}_2$  concentrations and lower, linear dependent of the  $\text{CO}_2$  concentration in the air (Smith, 1937). So the following differential equation holds for the net photosynthesis rate:

$$\frac{d[\text{CO}_2]}{dt} = A \cdot [\text{CO}_2] + B \quad (2)$$

Where A and B are constants. The solution for this equation is:

$$[\text{CO}_2] = C_1 e^{At} - \frac{B}{A} \quad (3)$$

Where A, B and  $C_1$  are constants. Another reason for the decreasing slope, although of less influence, is the leakage of the chamber. The equation for this effect happens to be of exactly the same form as equation 3, so correction for the dependence of the photosynthesis rate of  $\text{CO}_2$  concentration is also the correction for the leakage of the chamber.

Equation 3 is used to fit a line through the measurement points of the light measurements. Figure 6 shows the improvement that is made by using an exponential fit instead of a linear fit. To avoid effects of a decreased  $\text{CO}_2$  concentration on the absorption of  $\text{CO}_2$ , which is the net photosynthesis rate, the slope of the line where the  $\text{CO}_2$  concentration is 420 ppm, is calculated. This value is saved and used for further analysis. Also the average temperature in the chamber during the measurement, measured with an external thermometer, and biomass (if weighed) is saved

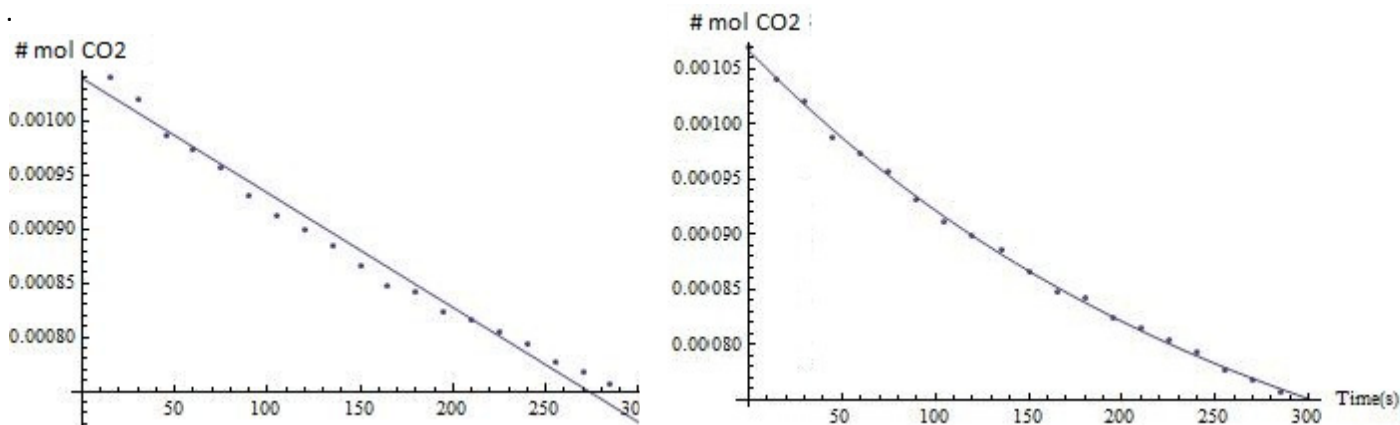


Figure 6. A linear and an exponential fit in the form  $[\text{CO}_2] = C_1 e^{At} - \frac{B}{A}$  are drawn through the measurement of 26<sup>th</sup> of May 6:41(wintertime). It is clear that the exponential line better fits the data points.

For the data analysis of the darkness measurements the linear plot is used because the exponential fits were generally no improvement to the linear fit. This can be understood as the darkness reaction has no CO<sub>2</sub> dependence. Also for the darkness measurements the biomass and temperature are appended to the data file.

First the darkness data of May 25 and 26, the *whole day measurements*, are further analyzed. The darkness data are plotted as CO<sub>2</sub> concentration in the chamber versus temperature. From this data an equation for the darkness reaction in  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  for *Elymus Athericus* will be derived as done by Klaassen and Spilmont (2012) with equations from Gillooly (2001):

$$D = a \exp(bT) \quad (4)$$

Where  $a$  is the *dark flux factor* and  $b$  is related to  $Q_{10}$ . The factor the dark flux increases with when the temperature increases with 10 °C is calculated with equation 5. The constants  $a$ ,  $b$  and the factor  $Q_{10}$  are found by another Mathematica program (appendix 2).

$$Q_{10} = \exp(10b) \quad (5)$$

Gross primary production is calculated (GPP) from the respiration and net ecosystem exchange (NEE) (equation 6). Respiration in equation 6 is calculated from temperature using equation 4 since respiration was not measured on every point where the NEE was measured. So if a light measurement is done at 22 °C, the respiration at 22°C is added to that value to find the GPP.

$$NEE = GPP - R_e \quad (6)$$

In this equation NEE is net ecosystem exchange and is positive if the CO<sub>2</sub> is absorbed. GPP is gross primary production, which is the light reaction. This value should always be positive.  $R_e$  is the respiration rate if CO<sub>2</sub> is *exhaled*, this value is positive.

The GPP will be modeled as a function of temperature and as a function of solar radiation; also this is done by a Mathematica file (appendix 3). First, the Vaisala data is linked to the solar radiation data from the Lutjewad measurement station. Then the GPP is plotted as a function of the solar radiation and fitted with the following equation (Jacobs, et al., 2007):

$$GPP = \frac{\alpha R_{in} GPP_{max}}{\alpha R_{in} + GPP_{max}} \quad (7)$$

Where  $R_{in}$  is the incoming short wave radiation,  $\alpha$  is the actual light conversion factor which can be calculated from the measured data, and  $GPP_{max}$  is the maximum assimilation rate.  $GPP_{max}$  is estimated first as the maximum value of GPP on May 25 and 26, and then this value is varied and determined on the value that gives the smallest standard deviation when fitting the data.

When these data are modeled, some points will deviate from the fitted line, mainly because the GPP also depends on temperature. To find a function that describes the GPP as function of solar irradiance and temperature, the deviation of each point from the line is plotted as function of temperature and is fitted using an equation by Webb (1974) (equation 8). The sum of equation 7 and equation 8 give an expression for GPP as function of temperature and solar irradiance.

$$\Delta[CO_2] = a - b(T - c)^2 \quad (8)$$

Where a, b, c are parameters depending on light intensity, plant type, and season for instance (Webb, et al., 1974). The function we got now, gives the increase or decrease of the GPP at a certain temperature. Now the dataset as function of solar radiation is corrected for these values (equation 9). The correction is done for all points and the data is plotted again. Since there has been a correction for the temperature, the fit is expected to be better than before.

$$GPP_{nieuw}[T_1, P_1] = GPP[T_1, P_1] - \Delta[CO_2] [T=T_1] \quad (9)$$

This multi-parameter fit is also used the other way around, so first a fit as function of temperature and then a correction for the solar radiation. First a fit is found in the form of equation 8. Secondly the deviation as function of solar radiation is plotted and fitted with equation 7. Then this fit is used to correct the data.

Above, the relation for the dark and light reaction has been found. From this relation it is possible to estimate the darkness reaction as function of the temperature, and the Gross primary production as function of temperature and solar radiation. The net ecosystem exchange is the sum of these two. Equation 6 is used to calculate the net ecosystem exchange (NEE) over a day for a certain area using the simulated values of GPP and Re as a function of solar radiation and temperature. Then this flux can be extrapolated for the area of interest. For example, the footprint of the Wageningen measurement setup. The results will be compared with the results of Wageningen and it will be determined where the deviation comes from.

The respiration rate and GPP of other measurement days were determined as function of solar irradiance, in the same way as for the whole day measurements. The light flux measurements will not be corrected for temperature. This is because there is no reliable temperature data for the most days, since the first measuring days the temperature was not measured with an external thermometer. The temperature data from the Lutfjewad station was useless during light measurements, because sunlight can make the temperature increase up to 10 °C in the chamber. Fortunately, the respirations measurements are done in darkness, so the temperature in the chamber will not increase, and the meteorological data will be useful.

The data of the other days are used to determine the influence of factors like seasonality, vegetation type and biomass. To get an estimation of the influence of seasonality, the data of each day is compared with the average data. This has been done by first finding a best fit through all the data and then comparing whether the data for each day of vegetation lies above or under the line. To find the influence of vegetation type, the same method is used.

The relationship between biomass and CO<sub>2</sub> flux is expected to be linear as long as the plant does not suffer of its own shadow (Streever, et al., 1998). However, a high leaf-area-index will cause an exponential relationship. Dried biomass will be plotted against the CO<sub>2</sub> flux and it is tried to find a correlation in the form:

$$\phi = A(1 - e^{-B \cdot m}) \quad (10)$$

Where A and B are constants and m is the biomass.

To find the reliability of the data, the measured data is compared with the EC data from Wageningen University. Their results give the NEE every half hour of the day in  $\mu\text{mol m}^{-2} \text{s}^{-1}$ , for an area of a few hectares. This area roughly consists of 5% tidal ditches, 15% *Spartina Towndensii* and 80% *Elymus Athericus* and *Festuca Rubra*(Appendix 4). So the total NEE is calculated as.

$$\text{NEE} = 0.8 \text{ GPP}_{\text{Elymus/Festuca}} + 0.15 \text{ GPP}_{\text{Spartina}} - (0.95 \text{ Re}_{\text{all species}} + 0.05 \text{ Re}_{\text{ditches}}) \quad (11)$$

## 6. Results and Discussion

### May 25th and 26th whole day measurements - Respiration

In figure 7 the respiration is plotted and fitted as function of temperature with an equation in the form of equation 4. This gives  $2.8294 \cdot e^{0.0307398 T}$  as best fitting curve. Then equation 5 is used to calculate  $Q_{10}$ , the factor the respiration rate increases when the temperature increases 10 °C. This factor is found to be 1.4. This value corresponds to the *normal* range for  $Q_{10}$  between 1.0 to 7.7 (Bonneville, et al., 2008) but deviates very much from the value 17 found by Vasilakis (2012) in the same area. One of the causes for this deviation might be that we measured in a different season and in different temperature range, but an even more important reason is that  $Q_{10}$  is calculated as a ratio between respiration rates. Vasilakis found respiration rates very close to zero, so a small absolute error in his measurement can give a huge relative error.

Notice that the data point at 17 °C deviates from the line the most. This point is the only measurement done in the evening: 19:44 PM. The other points are measured between 5:45 and 10:00 AM (wintertime). So this is an indication that there might be a difference in respiration rate between evening and morning. But since there is only one darkness measurement done in the evening, more research is needed to confirm this.

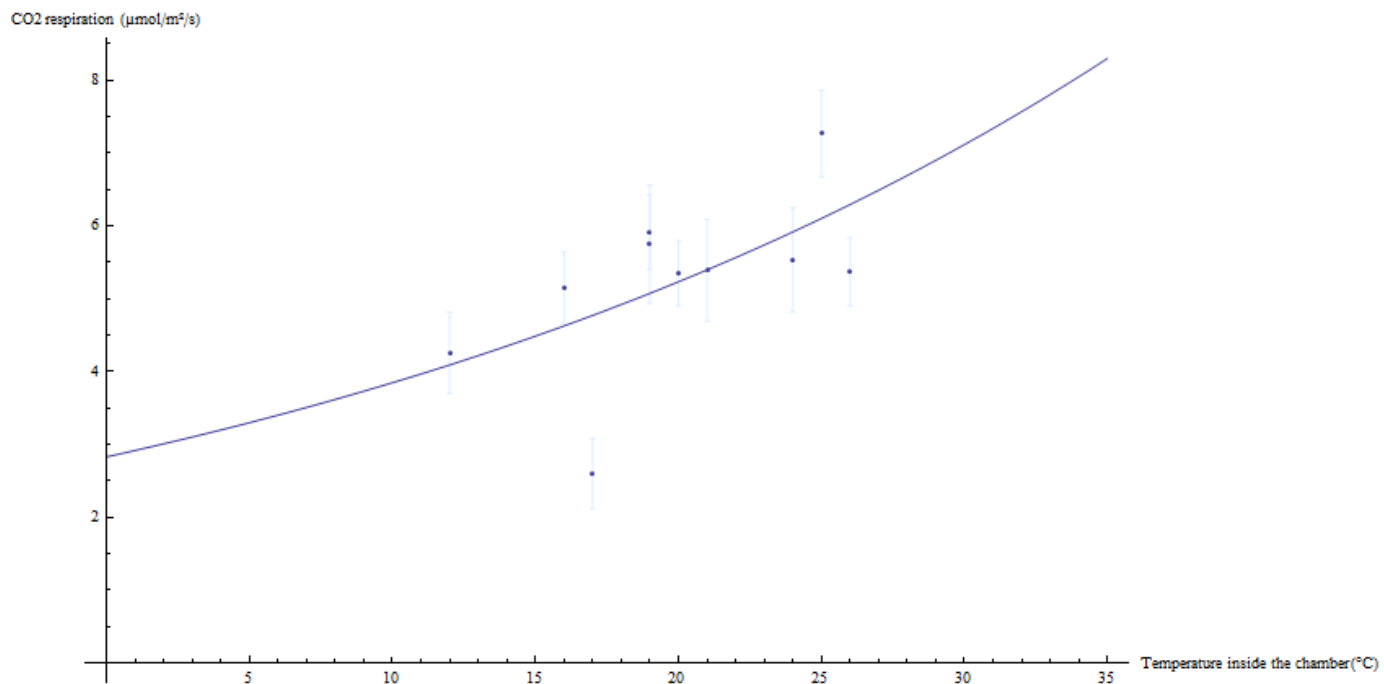


Figure 7. The dark flux of CO<sub>2</sub> of *Elymus grass* on the 25<sup>th</sup> and 26<sup>th</sup> of May versus temperature. The equation of the best fit through the points is:  $2.8294 \cdot e^{0.0307398 T}$  which gives  $Q_{10} = 1.4$ .

### May 25th and 26th whole day measurements - Gross Primary Production

To find an expression for the GPP the data, first the  $GPP_{max}$  had to be found. This value is found to be  $43 \mu\text{mol m}^{-2} \text{s}^{-1}$  from the data of May 25 and 26 (figure 8). Then a fit for GPP in  $\mu\text{mol m}^{-2} \text{s}^{-1}$  in the form of equation 7 is found.

$$GPP = \frac{0.26 R_{in} 43}{0.26 R_{in} + 43} \quad (12)$$

So the actual light conversion factor  $\alpha$ , is found to be 0.25. The scattering of the data is relatively high, with a standard deviation of  $8.2 \mu\text{mol m}^{-2} \text{s}^{-1}$ . Especially at higher solar radiation the difference becomes large. The reason that those values are lower than the line might be because of the high temperature in the chamber at that solar radiation. To estimate the influence of temperature the deviation of each data point from the best fit is plotted as a function of temperature in figure 9. Next the GPP data as function of solar radiation will be corrected with the best fit on temperature.

Figure 9 shows that high temperatures have negative effects on photosynthesis rate. A fit through the points gives the equation

$$\Delta GPP = -2.46 + 0.86 T - 0.031 T^2 \quad (13)$$

This equation gives that the ideal temperature for the photosynthesis is at approximately  $14^\circ\text{C}$ . This is much lower than the expected maximum between  $20^\circ\text{C}$  and  $25^\circ\text{C}$  (Hew, et al., 1969). One of the causes for the low ideal temperature might be that the vegetation is adapted to the low temperatures as a consequence of the proximity of the sea.

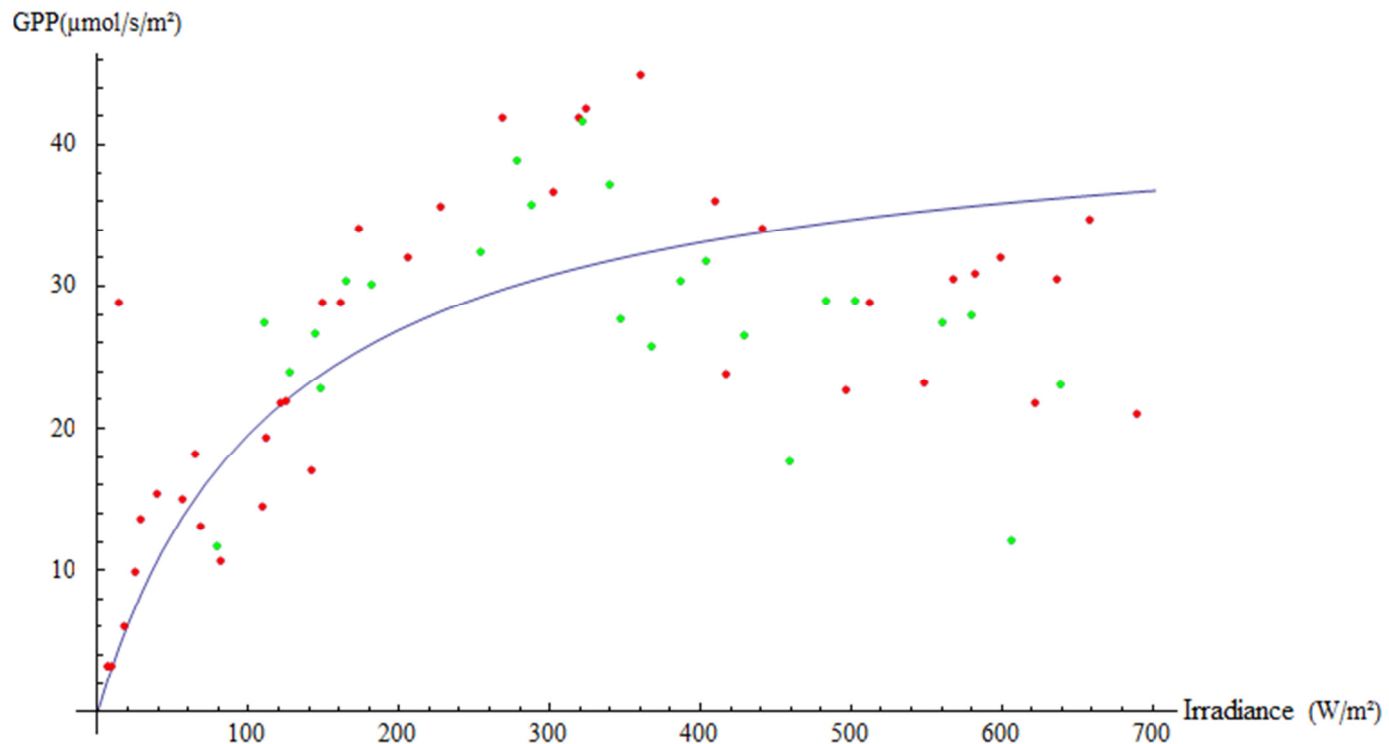


Figure 8 Gross Primary Production (GPP) versus incoming radiation on the data points of May 25<sup>th</sup> (red) and May 26<sup>th</sup> (green). Both data sets are in the same range, GPP values at low radiations lack for May 26<sup>th</sup> because that day measurements were started later. At higher values of solar radiation a decrease in GPP is shown, this might be caused by influences of high temperature. The equation for GPP in  $\mu\text{mol m}^{-2} \text{s}^{-1}$  becomes

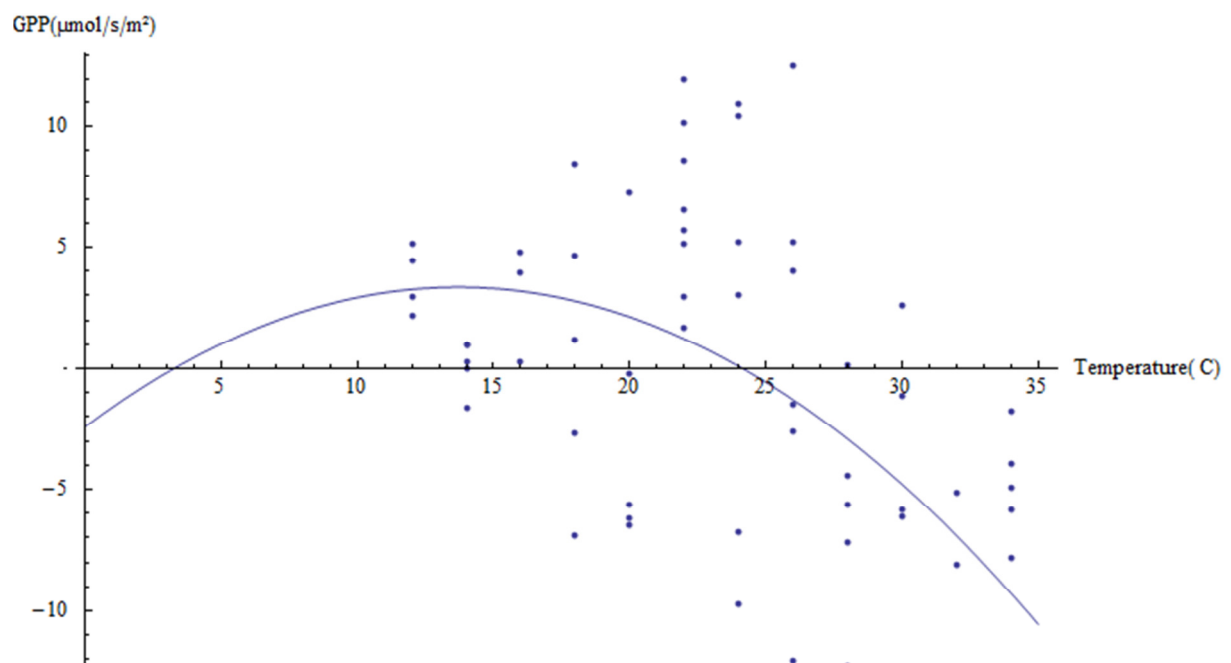


Figure 9. The deviation of the points in figure 8 is plotted against temperature. Also the best fit through the points is found in the form of equation 8. Remarkably, the optimum temperature is found to be only 14°C.

To see if the temperature really is a cause of the deviation of the data points in figure 8, those point are corrected with the line in figure 9. Figure 10 shows that the correction gives a slight improvement of the dataset. The standard deviation decreases from of  $8.4 \mu\text{mol m}^{-2} \text{s}^{-1}$  to of  $7.1 \mu\text{mol m}^{-2} \text{s}^{-1}$ . So temperature really has influence on the GPP but is not the main cause of the scattering of the data.

When the equation as function of solar irradiance and temperature are combined, the following equation is obtained for GPP:

$$GPP[T, Rin] = 0.26 * Rin * 43 / (0.26 * Rin + 43) - 2.46 + 0.86 T - 0.031 T^2 \quad (14)$$

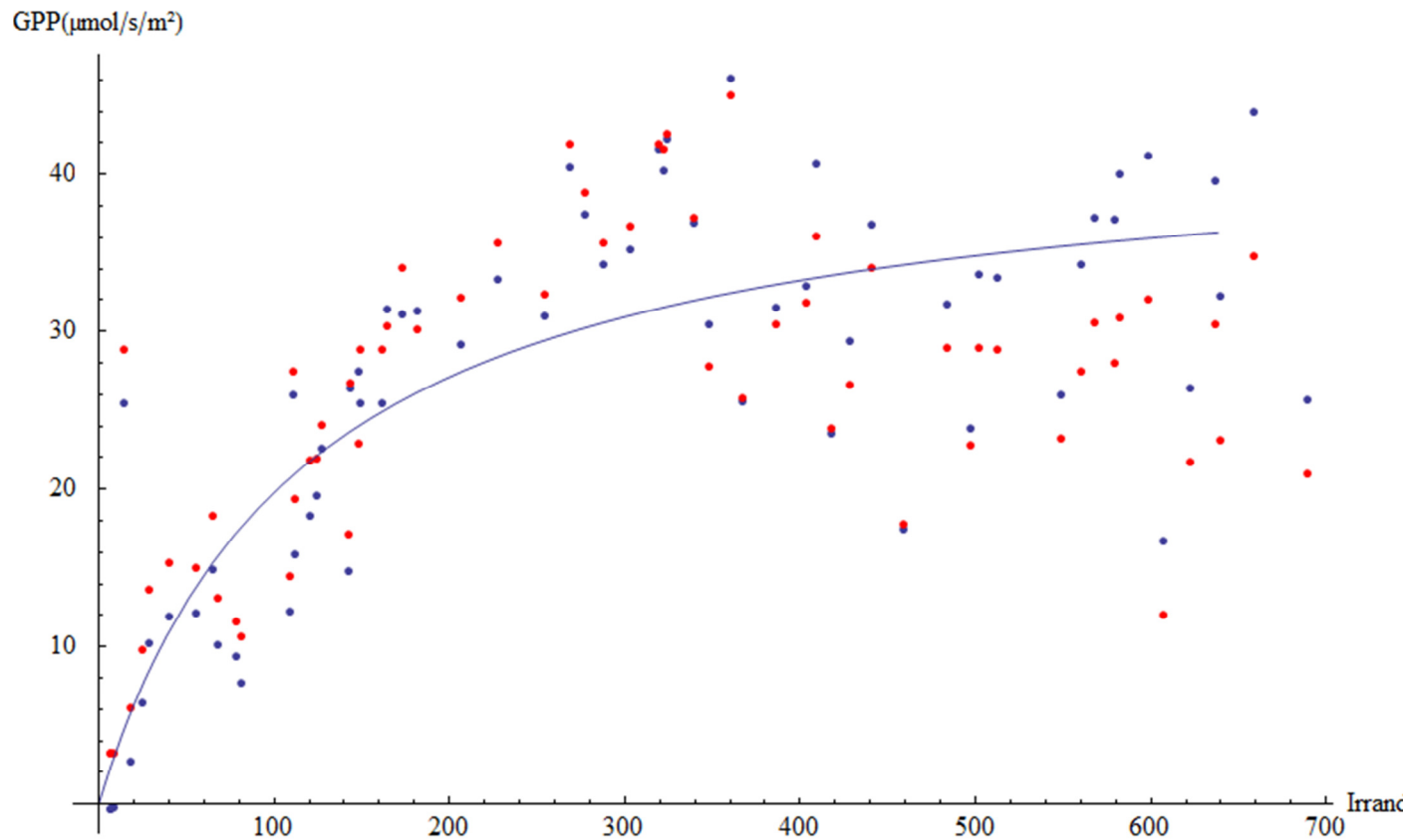


Figure 10. Original data with a standard deviation of  $8.2 \mu\text{mol m}^{-2} \text{s}^{-1}$  (red) and corrected data (blue), standard deviation of  $7.0 \mu\text{mol m}^{-2} \text{s}^{-1}$  for the temperature are shown. Especially for higher temperatures the correction shows its results clearly.

The data from May 25 and 26 is also plotted as function of temperature and fitted with equation 8 (figure 11). There clearly is some increase in GPP for higher temperatures, but the reason for that amount of increase is that the temperature tandem with the solar radiation. The influence of temperature on GPP is much smaller than the increase of solar radiation, so this plot is not a representative measure for GPP as function of temperature, and therefore can't be used for multi parameter fitting.

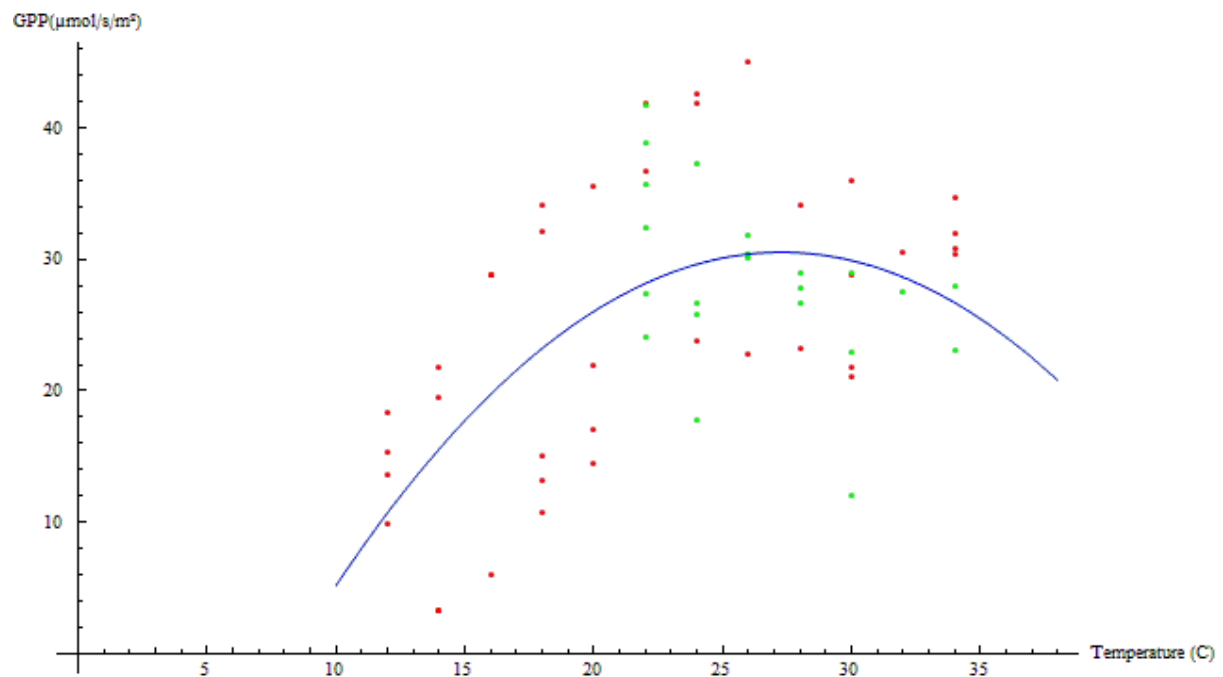


Figure 11. GPP of May 25<sup>th</sup> (red) and May 26<sup>th</sup> (green) plotted as function of temperature. The reason for parabolic shape of the data points is mainly that higher temperatures belong to higher irradiation in general. So the fit is not a measure for GPP as function of temperature.

The disadvantage of multi-parameter fitting is that the best fit will not change due to this correction, because the average value of the correction fit is zero. So the first best fit made will be the final fit. This means that if a function of two variables,  $f(x,y)$ , has a great dependence of both  $x$  and  $y$ . A plot of  $f$  as function of only  $x$  (but with varying  $y$ , especially if  $y$  is not varying randomly, as in our case) is not representative for the function  $f$ . Luckily in our case GPP is mainly dependent of the light intensity, so the best fit as function of will be a reasonable approximation of GPP.

This is also why it didn't work to start with the GPP as function of temperature, and then execute the correction for solar radiation. Because the first fit was not a good representation of the GPP as function of temperature. To get better approximations for GPP as function of temperature and time one of the two variables should be kept constant. I tried to sort the data on temperature and plot GPP as function of solar radiation appendix3. But the number of data points per temperature interval was far too low to get results.

The NEE for all days can be estimated using equation 9 and the equations for the darkness reaction and GPP. The equation for the respiration is  $2.8294 \cdot e^{0.0307398 T}$ , we now assume that the reaction is only dependent of temperature and not of any other factor like moment on the day. To estimate the darkness reaction over the day the meteorological data from the Lutjewad Station is used (Appendix 4).

The GPP can be calculated with equation 14, also found in the previous section. From GPP and respiration, the NEE is calculated using equation 6. The average value for the NEE on May 25 and 26 is determined as  $14 \mu\text{mol m}^{-2} \text{s}^{-1}$  for the measured area Elymus Athericus. This value is very high compared to the value of  $2 \mu\text{mol m}^{-2} \text{s}^{-1}$  found by Vasilakis (2012). Reasons for this difference are that Vasilakis was measuring in the autumn and winter, while my research is done in spring. But also: all my measurements were done on the same spot, so the grass around the measuring spot was

damaged during the day, which reduced the shading from those plants. Later is shown that the average value for all species lies closer to the value found by Vasilakis.

### All measurements- Soil respiration

The soil respiration for all measurements days and all species is plotted in figure 12. This figure shows both the measurements directly after the base is placed in the ground and the respiration rates after one week. Typically all the soil respiration rates that lie close to zero belong to the measurements after one week. The average respiration found in my measurements is  $4.1 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $5.3 \mu\text{mol m}^{-2} \text{s}^{-1}$  if the measurements after 1 week are not taken into account. If only the measurements after one week are considered, the average rate becomes  $0.2 \mu\text{mol m}^{-2} \text{s}^{-1}$ . Renée Hermans did soil respiration measurements in the same period as I did. She found an average value of  $7.2 \mu\text{mol m}^{-2} \text{s}^{-1}$  on May 25 as an average of 16 measurements. The soil respiration when measured directly after cutting the vegetation corresponds to the measurements of Hermans. Reasons for the difference between the results after one week, and directly after the vegetation has been cut can be drying of the soil and the roots of the vegetation, but also an increased respiration due to disturbance of the soil.

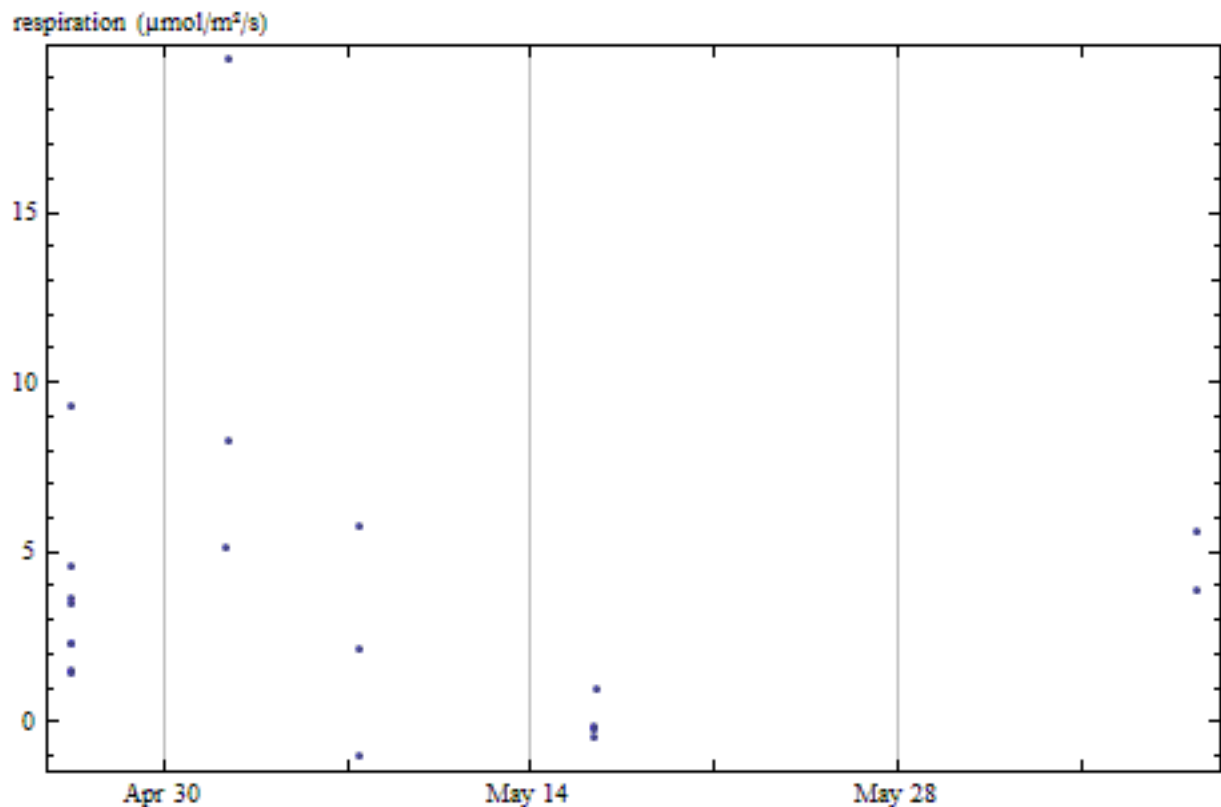


Figure 12 soil respiration plotted per day. The lowest value on the 7<sup>th</sup> of May and all values of May 16 are results of measurements of soil respiration a week after the vegetation was cut away. The average value of all measurements is  $4.1 \mu\text{mol m}^{-2} \text{s}^{-1}$ , when only the measurements after one week are taken into account the average becomes  $0.2 \mu\text{mol m}^{-2} \text{s}^{-1}$ .

### All measurements- Darkness Respiration

Figure 13 shows respiration of *Elymus Athericus*. Again, a high scattering is observed. The standard deviation of the points from the best fit,  $20.3281 e^{0.078384 T}$ , is  $2.5 \mu\text{mol m}^{-2} \text{s}^{-1}$ . This gives a factor of 2.2 for  $Q_{10}$ . In the ideal case, this value should be the same as the value for  $Q_{10}$ , found during the whole day measurements, which is 1.4. High scattering of the data points is probably the cause of the difference in  $Q_{10}$ . Many more measurements are needed to get accurate results.

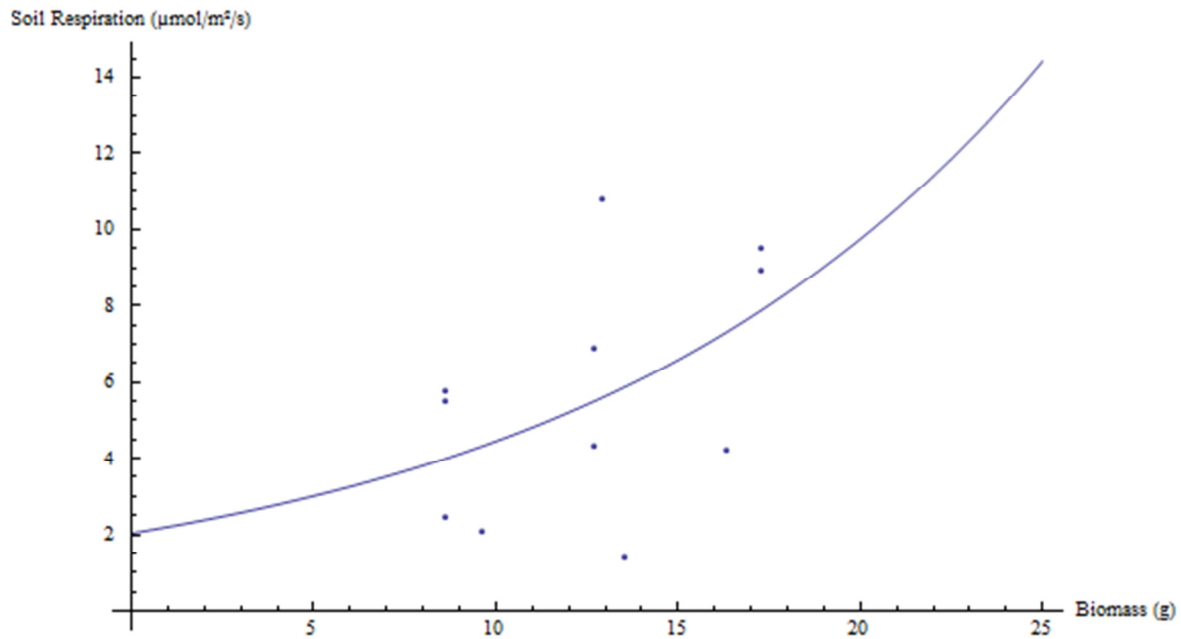


Figure 13. A plot of all *Elymus* respiration as a function of temperature. The best fit through the points in the form of equation 4 is  $20.3281 e^{0.078384 T}$  this give  $Q_{10}$  2.2. The standard deviation of the points from the fit is  $2.5 \mu\text{mol m}^{-2} \text{s}^{-1}$ .

### Respiration of all species

The respiration of all species is plotted in figure 14, it was tried to find a line through all points, but since there were some values very close to zero (even less than zero) the fit through the points was not a good representation of the data. Therefore, the fit through the data points of *Elymus* is shown again. To estimate the influence of species on respiration the average difference between the best fit through the *Elymus* data and the other data point is calculated (table 1). The values less than zero might be due to almost zero respiration and random errors in the measurement setup. These values will be taken into account since all values will have these random errors. The average respiration of *Festuca Rubra* lies significantly under the *Elymus* fit. The reason for this difference could be that *Festuca Rubra* is growing slower than *Elymus*. The average value of *Spartina* lies well above the line, but also has a wide scattering. The scattering is probably caused by difference in measurement data; the two highest points are measured on the 2<sup>nd</sup> of May, when there was no biomass above ground at all and the respiration measured, is caused by decomposition of the dead material of last year. The other points are measured on June 8, when the plants just started growing, and the most of the older biomass was already gone. For that day the average value of respiration is also a bit below the *Elymus* fit, probably because the amount of vegetation was very small.

Vegetation Species	Deviation from best fit through Elymus
Elymus Athericus	0.0 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (trivial)
Spartina Towndensii	-1.7 $\mu\text{mol m}^{-2} \text{s}^{-1}$
Festuca Rubra	-3.3 $\mu\text{mol m}^{-2} \text{s}^{-1}$

Table 1. Difference of respiration rates of several species, with respect to Elymus.

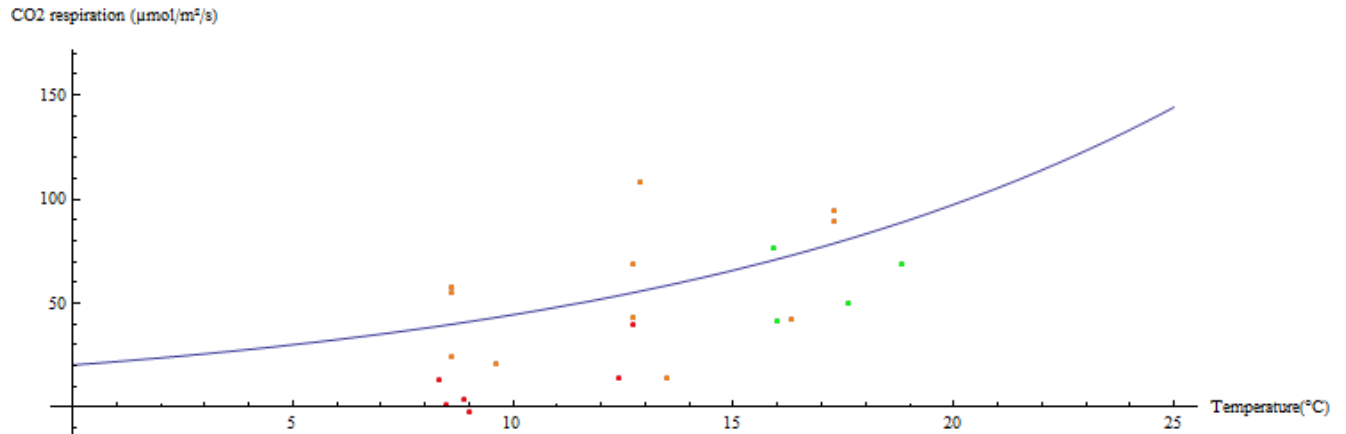


Figure 14. Respiration of Elymus Athericus (orange), Spartina Towndensii (green) and Festuca Rubra (red) with the best fit through the Elymus data:  $20.3281 e^{0.078384 T}$ . All Festuca Rubra data lies under the curve. The Spartina data, also lie below the curve on average.

### Respiration and Biomass

The respiration for Elymus is plotted versus dried biomass of the dried living vegetation (figure 15). Although the scattering of the data is very large, a fit through the points is found:  $R_e = 2.1 \cdot \text{mass}$ . The large scattering is caused by difference in temperature. To get better results more data is needed. But the problem with collecting many data, is that it is very time consuming.

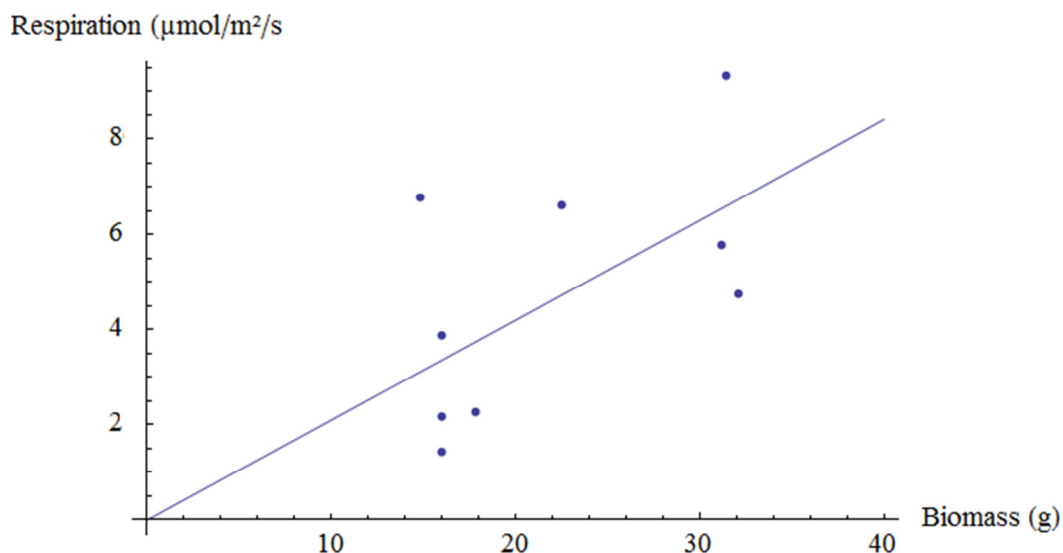


Figure 15. Respiration rate plotted versus biomass. The biomass is the total living dried biomass on an area of 28x28cm.

## All measurements- GPP

In figure 16, all measurements done on Elymus are plotted and with equation 7 the best fit is found. The actual light conversion factor is found to be 0.067, which is much lower than the factor found during the whole day measurements. The fit has a large scattering: a standard deviation of  $7.1 \mu\text{mol m}^{-2} \text{s}^{-1}$ . The data is ordered by measurement day. Orange dots are measurements from April 24, green from May 7, red dots May 16, purple dots are measured on the 8<sup>th</sup> of June. For every day the average deviation from the best fit line is found. High variations from day to day are found, but on average the productivity increased during the measurement period from April to June. Probably factors like spatial variability and temperature are causes of the high variation per day.

The measurements during overcast have a higher productivity than expected from the plot. That supports the assumption that vegetation is relatively productive under diffuse light (Farquhar & Roderick, 2003).

Measurement	Average deviation of GPP
April 18	$-3.7 \mu\text{mol m}^{-2} \text{s}^{-1}$
May 7	$-12.2 \mu\text{mol m}^{-2} \text{s}^{-1}$
May 16	$1.4 \mu\text{mol m}^{-2} \text{s}^{-1}$
June 8	$-0.6 \mu\text{mol m}^{-2} \text{s}^{-1}$
All Shaded Measurements	$4.1 \mu\text{mol m}^{-2} \text{s}^{-1}$
Measurements of May 25 and 26 (not plotted)	$12.2 \mu\text{mol m}^{-2} \text{s}^{-1}$

Tabel 2. The deviation of GPP per day, compared to the average GPP.

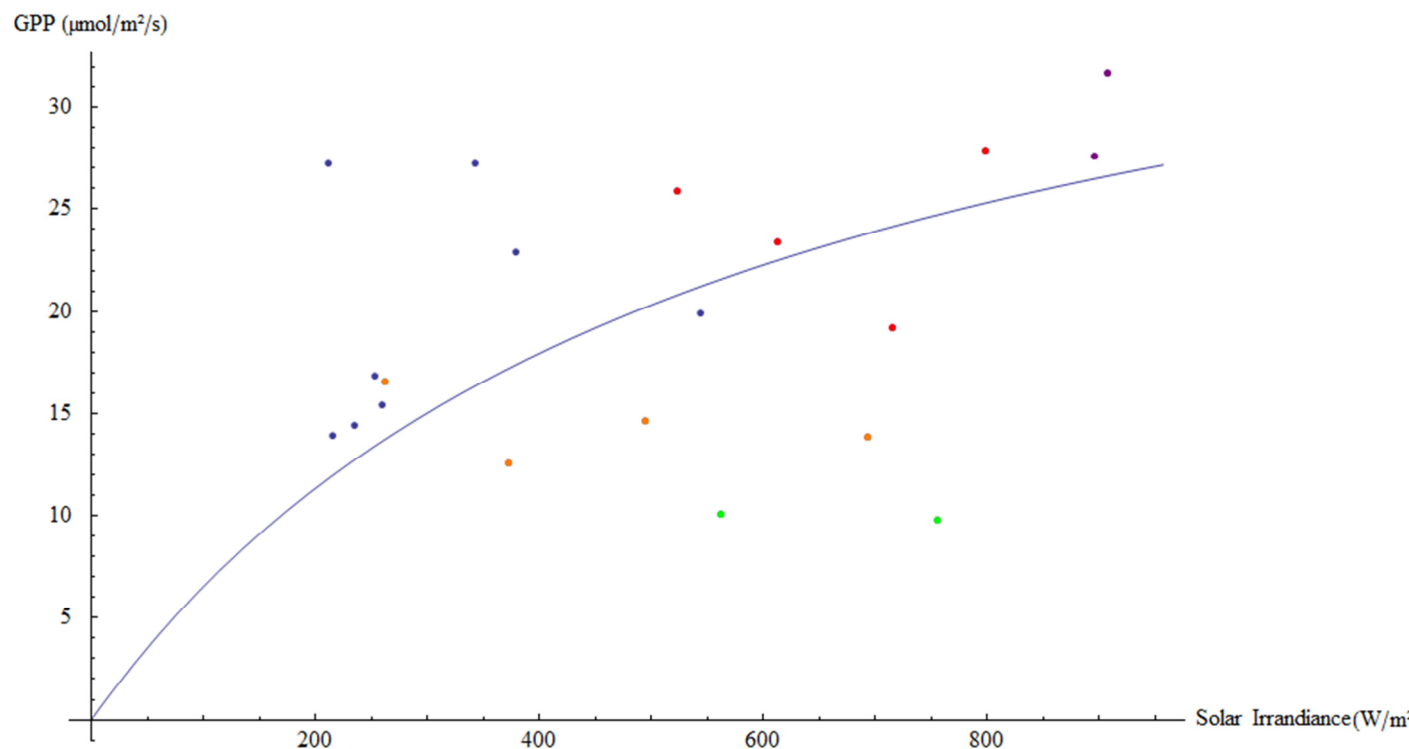


Figure 16. GPP of all Elymus light measurement versus solar irradiance. Orange dots are measurements from April 24, green from May 7, red dots May 16, purple dots are measured on the 8<sup>th</sup> of June. And blue are all measurements done during overcast. Blue dots typically lie above the best fit line, which is evidence for the theory that the vegetation is more efficient with diffuse light.

## GPP of All species

In figure 17 the GPP is plotted of all light measurements. The line in the graph is the best fit for only the Elymus data. To estimate the CO<sub>2</sub> production for different species, the deviation of the Festuca and Spartina data points are calculated and shown in Table 3. The reason for the extremely low gross primary production rate of Spartina is that only a few stems were growing during the measurement. A data point from Spartina is observed to have a GPP of 40  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . It is not known where this high rate comes from, but because this was the only spot where such a high GPP was measured, this data is removed from the data.

Vegetation	Deviation from the best fit through Elymus
Elymus Athericus	0 $\mu\text{mol m}^{-2} \text{s}^{-1}$
Festuca Rubra	-0.8 $\mu\text{mol m}^{-2} \text{s}^{-1}$
Spartina Townsendii	-11 $\mu\text{mol m}^{-2} \text{s}^{-1}$

Table 3. Deviation of the GPP for different vegetation species. The GPP of Festuca Rubra is found to be very close to that of Elymus Athericus, while Spartina Townsendii has a much lower gross primary production.

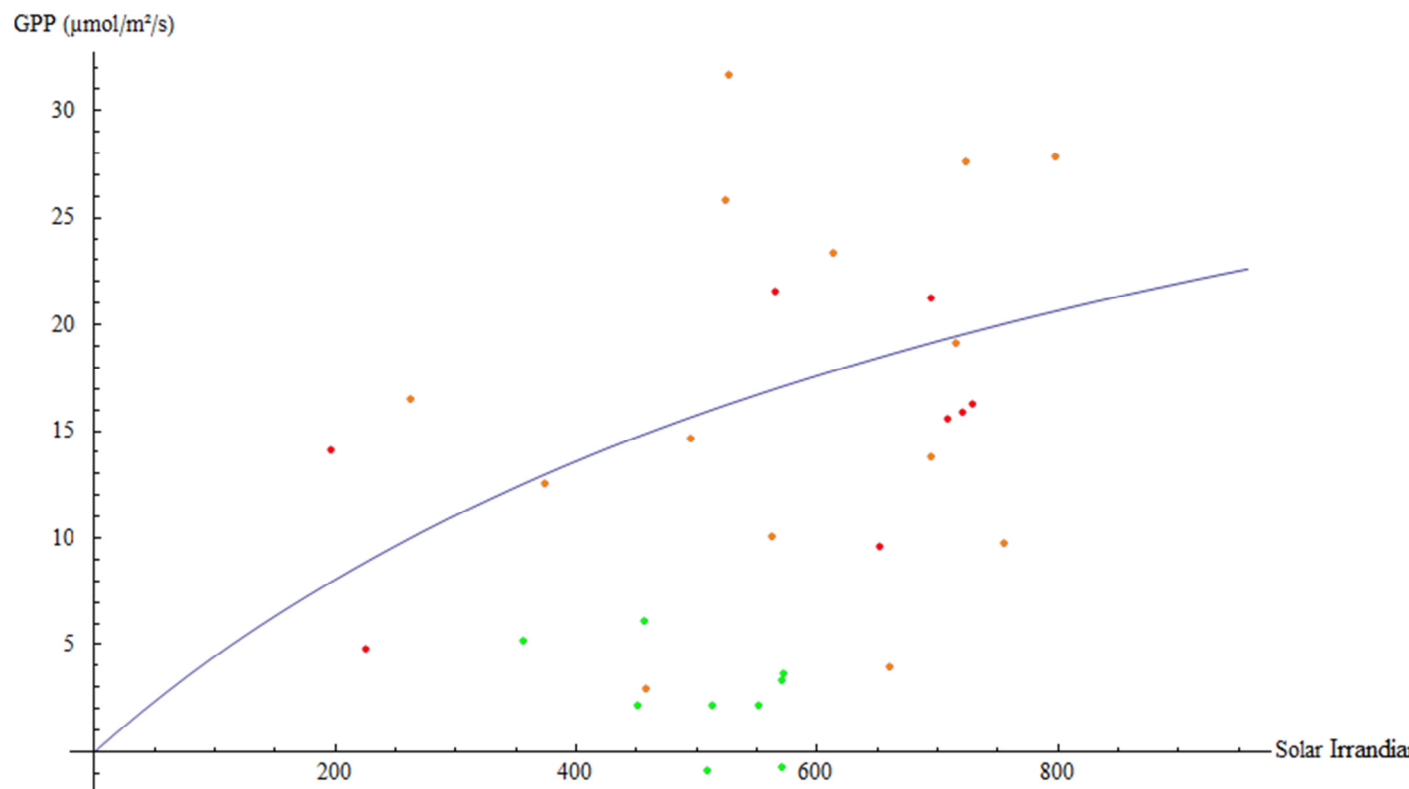


Figure 17. All GPP measurements plotted against solar radiation. The green points belong to Spartina, orange to Elymus, and red points to Festuca Rubra. The blue line is the best fit through the Elymus data.

### Estimation of NEE

With the equations for the darkness reaction and GPP for Elymus for all days the NEE can be estimated using equation 9. The equation for the respiration is  $2.03281 e^{0.078384 T}$ , we now assume that the reaction is only depending on temperature and not of any other factor, like time of the day. The calculated dark reaction is shown in figure 18.

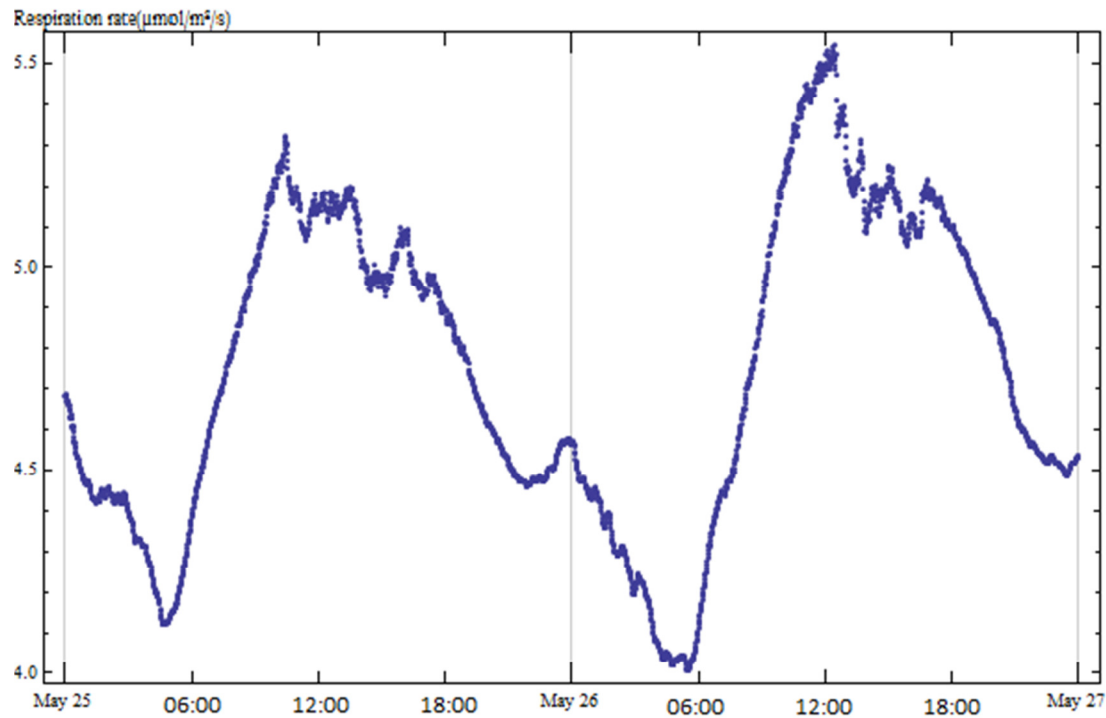


Figure 18. Respiration rate is calculated from temperature and equation  $R = 2.03281 e^{0.078384 T}$  for the 25<sup>th</sup> and 26<sup>th</sup> of May.. As expected the estimated respiration rate is lowest during the coldest moment of the day.

The GPP has been calculated with equation 12 for all data. Also here we assume there is no temperature dependence. After the GPP is calculated, the respiration is subtracted from it to get the NEE figure 19. In this graph also the data found by Renee Hermans from Wageningen University are plotted. Both data sets are very alike. Both respiration rate and the soil respiration calculated are very close to the EC data. The goodness of the fit is unexpected, since the scattering of my measurements was very large and only solar radiation is used as variable. My data is pretty much symmetric (because the amount of solar radiation is symmetric). The EC data shows a maximum CO<sub>2</sub> sequestration *on the right side* of the maximum solar radiation. This is probably caused by the temperature. It would have been better to calculate the NEE as function from temperature also. An expression like equation 14 should be obtained then. Unfortunately, for most data the temperature inside the chamber is not known, so the temperature dependence of the GPP for *all days* could not be found. It has been tried to correct the data with the temperature dependence of the data of May 25 and 26 (equation 13). However, equation 13 was found out to be unusable for the temperature dependence of *all days*, since the plot did not improve when the correction with equation 13 was included.

Very remarkably: on the EC data (figure 19) there is a decrease in the (the absolute value of the) NEE rate during both days between 8:30 en 11:00 AM. At that time the solar radiation is between 420 and 800 W/m<sup>2</sup>. My data shows also a dip at that amount of solar radiation (figure 8). (Radiation between 420 and 800 W/m<sup>2</sup> is only measured in the morning so the two dips correspond to the same time.) A possible cause could be the influence of high and low tide. On May 25 and 26 low tide in Lauwersoog was at respectively 7:36 and 8:06 (Meetadviesdienst, 2012). Probably it was delayed some time by the part of the salt marsh closer to the sea, so a cause for the dip in the EC data and in my data could have been the low tide (Kathilankal, et al., 2008). On the other hand, at 20:00 PM no decrease in production is shown, but that's probably because the production is already very low at that time. With only this data it is not possible to be sure whether the dips in my data and the EC data are linked, and if they are, what the cause of this dip is. To find out whether the dips are linked *a whole day measurement* should be executed, for example, when it is high tide at 8:00 o'clock.

The average CO<sub>2</sub> flux measured for all species with the solar irradiance of May 25 and 26 is calculated on 4 µmol m<sup>-2</sup> s<sup>-1</sup>. The value for Elymus found on the 25<sup>th</sup> and 26<sup>th</sup> of May of 14 µmol m<sup>-2</sup> s<sup>-1</sup> is much higher because those days there was only measured on one location, where the surrounding vegetation was damaged, so there was more irradiance on the grass. Probably, factors temperature, day in the season and spatial variability were ideal for those measurements on May 25 and 26. Another reason why the sequestration rate for all species is lower than for the Elymus of May 25 and 26, is that Spartina grass was a carbon source during the measurement period.

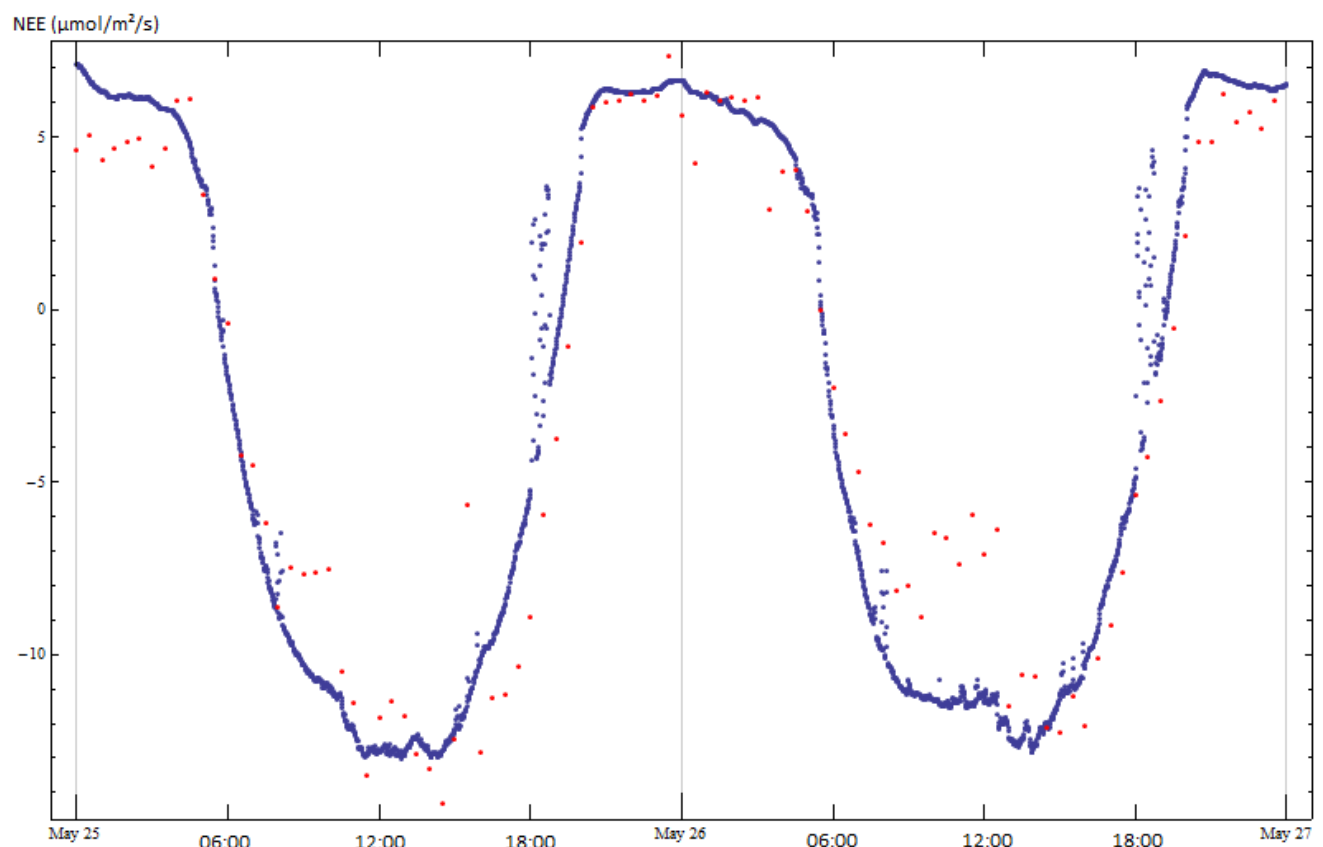


figure 19. The NEE calculated by equation 4, 6 and 7 (blue) and data from Eddy Covariance measurements of Wageningen University (red). The peak in the blue graph at 18:00 is probably caused by shading of the tower (lower solar irradiance gives lower CO<sub>2</sub> sequestration by vegetation). The red data shows on both days some decrease in NEE from 8:30 to 11:00AM. Negative values mean that CO<sub>2</sub> is sequestered.

## Respiration of tidal ditches

In the wet tidal ditches no respiration was measured. In the dry ditches however, CO<sub>2</sub> was emitted from the soil with an average rate of 6.5 μmol m<sup>-2</sup> s<sup>-1</sup> and a standard deviation of 1.3 μmol m<sup>-2</sup> s<sup>-1</sup>. Most of the ditches are the wet; only 0.3% of the total area is made up by dry ditches, while the wet ditches cover around 5%.

## General errors

All results show a relative large scattering in data. Especially when data set are the results of measurements on different days, different positions, different temperatures and different types of vegetation. So all these factors have influence on the respiration rate. Because of the number of the variables it was often hard to distinguish the effect of one of the variables, so the results found are prone to large errors.

If these factors were circumvented, still errors were caused by the disturbance of the measurement location, by pushing the base in the soil, and leakage of the chamber. Evaporation might have been a cause of errors, but the significance seemed to be small. Also the uncertainty of the instrumentation is a cause of errors.

## Conclusions

The best fit for the respiration rate of Elymus at May 25 and 26 in μmol m<sup>-2</sup> s<sup>-1</sup> is:  $2.8294 * e^{0.0307398 T}$ . The plot of this graph corresponds to the Eddy Covariance data found by measurements of Wageningen University.

The best fit for the GPP on May 25 and 26 in μmol m<sup>-2</sup> s<sup>-1</sup> is:

$$GPP[T, Rin] = 0.26 * Rin * 43 / (0.26 * Rin + 43) - 2.46 + 0.86 T - 0.031 T^2$$

It is shown that solar radiation is not the only factor in the GPP, temperature is shown to be significant to. Maybe tidal variation is a factor in GPP.

The carbon flux of the measured Elymus grass over May 25 and 26 is found out to be 14 μmol m<sup>-2</sup> s<sup>-1</sup>. The carbon flux for All species over May 25 and 26 is found out to be 4 μmol m<sup>-2</sup> s<sup>-1</sup>.

For the data of the other days, the best fit through the GPP lies lower than for the *whole day measurements* also the error in these values is larger.

There is a significant difference between soil respiration immediately after the base is pushed into the soil and a week later.

During May 25 en 26 the Salt Marsh as a whole is found to be a sink for CO<sub>2</sub> but the parts where Spartina grew was found to be a source.

During this measurement period there was no significant difference in production between Festuca Rubra and Elymus Athericus. Because Spartine Towndensii just started growing, low leaf area so a low photosynthesis rate, the production of the species was much lower than the other two species.

Eddy Covariance Data and Closed Chamber data of the NEE match very well, but this might be coincidentally since the scattering of the closed chamber data was very large.

Tidal ditches do not emit CO<sub>2</sub>; the dried up ditches do emit CO<sub>2</sub> at an average rate of 6.5 μmol m<sup>-2</sup> s<sup>-1</sup>, but because of their rare presence, they are not a significant factor in the total carbon balance of the marsh.

## Recommendations

It will be interesting to find out whether tidal variation has consequences for the CO<sub>2</sub> production, and whether it is an explanation for the decrease in GPP as measured on May 25 and 26.

To get a better growing model for Elymus vegetation measurements the temperature should be kept constant while the solar radiation is varied. This is very hard to do outside a laboratory. I also tried to sort for temperature and then plot measurements with the same temperature as function of solar radiation, but a lack of data point per temperature interval made the results useless

The thermometer in is Vaisala is not a measure for the temperature in the chamber during light flux measurements. Also the data from the Lutjewad weather station is not representative for the temperature in the chamber during light measurements, since the temperature in the chamber is rising very quickly, sometimes with more than 10 °C in 5 minutes. So an external thermometer is needed to measure that.

One of the measurements indicated a difference in respiration rate between daytime and nighttime. It might be interesting to find a ratio between these two, because for a good estimation of the total carbon balance of the salt marsh it is important to know what the CO<sub>2</sub> flux is during nighttime.

Use more bases and keep those on measurement positions to better research the effects of disturbance of the soil.

If this multi-parameter fitting is done again for this research, it might be better to use, instead of equation 8, another equation to fit the deviation of the data. In the form:

$$\Delta[CO_2] = (a - b(T - c)^2) * R_{in}/R_{max}$$

Where R<sub>max</sub> is the maximum solar irradiance during the measurements. This might be better because at low solar radiation the absolute deviation will be smaller than at high solar radiation.

## Measurement days

The measurements are done during 8 days over a period of 7 weeks. There is a total of 8 weeks for measuring; the measurements are done on variable days. The measuring weeks are:

	Planned Measurements	Peculiarities
<b>April 11</b>	Learn to work with the measurement equipment.	
<b>April 18</b>	Leakage measurements. Learn to work with the measurement equipment.	To get impression of environmental parameters like temperature, sun irradiance.
	Reparation of equipment.	
<b>April 26</b>	Elymus Athericus: Soil, clouds, direct sunlight. CO <sub>2</sub> flux of the tidal ditches	
<b>May 2</b>	Measurements on the fustuca rubra and Spartina townsendii, soil, clouds, direct sunlight.	
<b>May 7</b>	More measurements on Elymus, and fustuca rubra. Dark and light; biomass will be stored.	
	Leakage measurement of the repaired chamber.	
<b>May 16</b>	More measurements on Elymus, en fustuca rubra. Dark and light; biomass will be stored	Concentrate especially on Elymus Athericus
<b>May 25 &amp; 26</b>	25 <sup>th</sup> and 26 <sup>th</sup> of may measurements of dark flux and light flux of Elymus from sunrise to 12 o'clock and from 7 o'clock to sunset. Also measure temperature with separate thermometer.	
<b>June 8</b>	Measurements to Elymus and Spartina	

## Measurement Location

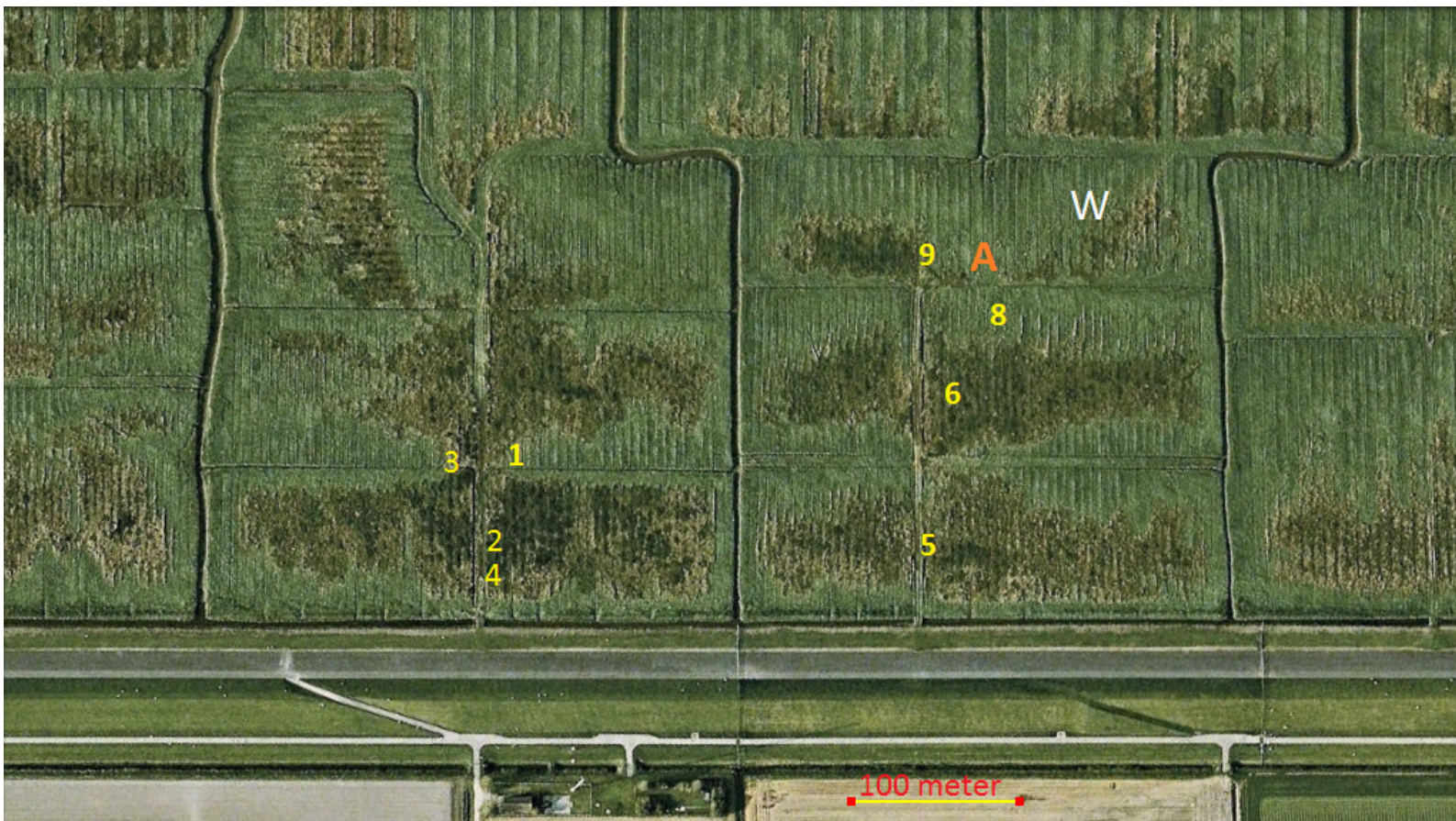


Figure 20. All measurement places are shown; on the bottom of the picture the Lutjewad weather station is shown. W is the position of the measurement setup from Renee Hermans from Wageningen University. A is the position where my “whole day measurements” were done. In the vicinity of position 1 all measurements of April 26 are done, and the measurements of the tidal ditch. On position 2 and 3 the measurements of *Festuca Rubra* are done on May 2. On position 4 *Spartina Townsendii* has been measured on May 2. Position 7 is a position of a dried ditch, measured on the 7<sup>th</sup> of May. In the area of position 6 measurements are done to *Spartina Townsendii* on June 8. Position 8: *Elymus* is measured on June 8, and *Festuca Rubra* is measured on the 7<sup>th</sup> of May. In the vicinity of number 9 *Elymus* is measured on the 16<sup>th</sup> of May and on May 7.

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