ClimGrass - an innovative field experiment to study the consequences of climate change in grassland

In recent years, a worldwide unique, multifactorial field experiment was developed and realized at the Agricultural Research and Education Centre (AREC) Raumberg-Gumpenstein (Austria) with the participation of numerous domestic and foreign experts (Herndl et al., 2010; 2011; Pötsch et al., 2019).

Experimental design and technical equipment

On a total of 54 experimental plots, increases in temperature and atmospheric CO_2-concentration as well as dry periods can now be simulated in various gradations and combinations (Figure 1). For field experiments, classical experimental designs such as Latin squares, grid systems or block systems are usually used to test individual elements/variations randomly and in multiple repetitions. During the design of the first, original part of the ClimGrass experiment (Lysi-T-FACE) it was already clear that due to the high number of factor combinations (3 temperature levels * 3 CO_2 levels) and the additional installation of monolythlysimeters on 6 plots, a classical design cannot be used for cost reasons. Therefore, in cooperation with Prof. Dr. Hans-Peter Piepho (Biostatistics Group, Institute of Crop Science, University of Hohenheim, Stuttgart) a response-surface design and thus an approach was selected that was originally developed and used for technical applications (Piepho et al. 2017).

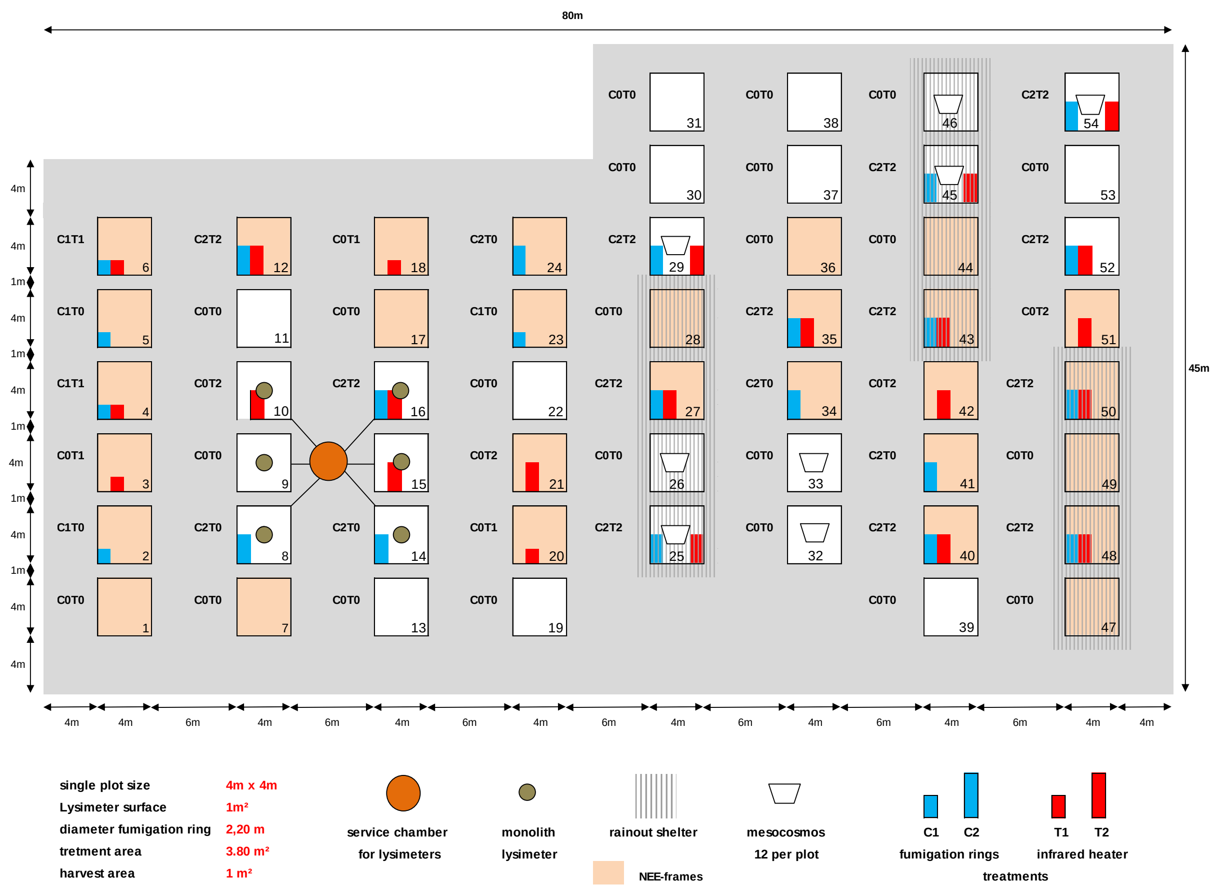

Figure 1: Schematic design of the ClimGrass-experiment

The air temperature is varied in three gradations, namely ambient (= T0, which corresponds to the respective current temperature), + 1.5°C (= T1) and + 3°C (= T2). Heating is carried out all day and all year round and is only suspended when there is a continuous snow cover from a height of 10 cm. The regulation of the infrared radiators used is based on sensor measurements in the center of the test plots and is controlled by the control software "LabView" (National Instruments) via dimmers. The CO_2-concentration of the atmosphere is also tested in three gradations: ambient (= C0, which corresponds to the current CO_2-concentration), + 150 ppm (=C1), + 300 ppm (=C2) (ppm means parts per million, i.e. one millionth). The fumigation is only carried out during the day as soon as an irradiation energy of 50 W/m² is reached and only during the vegetation period from March to the end of November. From a wind speed of 1.5 m/sec the CO_2-supply is interrupted. The combination C2T2 (i.e. + 3°C and + 300 ppm CO_2) corresponds to the climate projection whose occurrence seems most probable for the Alpine region at the end of the 21st century (Gobiet et al., 2014) and is therefore called "future climate" in the internal language of the ClimGrass Project.

The experimental plots are heated by six hexagonally arranged infrared radiators each. Via a centrally arranged fumigation ring (mini-FACE system) the ambient air enriched with CO_2 flows into the plant stand (Figure 2). The entire heating, fumigation and associated sensor technology is mounted on a height-adjustable support frame, which is adapted to the height of the vegetation changing in the course of the individual growths at intervals of several days. During harvesting, service and sampling activities, the support frame can be swung out into the existing intermediate paths via the cable-bearing column, thus allowing unhindered access to the test plots. To eliminate a possible blower effect (Pinter Jr. et al., 2000), all untreated plots are also equipped with a fumigation ring through which ambient air flows and all unheated plots are also equipped with unconnected dummy heaters to eliminate any shading effects.

The added CO_2 has an isotopic signature (^{13}C) that is distinguishable from atmospheric CO_2 and comes from a special source. This therefore requires a separate delivery in intervals of about 8-10 days, since there is only a tank volume available on site for the storage of 5 t CO_2 for reasons of cost and space. Each individual CO_2-batch is sampled and both the quality of the added and ambient CO_2 is verified in the form of the isotope signature at the University of Vienna. Since each plot is heated and fumigated individually, this requires an enormous amount of control and regulation with appropriate programming in the background. The regulation of the CO_2 supply is based on sensor measurements in the center of the fumigation rings and is controlled by proportional valves using the control software "LabView" (National Instruments).

Facility performance

For many decades, the AREC Raumberg-Gumpenstein has successfully been conducting field trials on a wide range of questions and topics in the field of grassland management. Many of these trials include different gradients in terms of fertilization and/or utilization and require a lot of experience and corresponding experimental know-how for their correct execution and application. However, the implementation and the most precise achievement of the increase in temperature and CO_2 concentration in the ClimGrass experiment is a very special challenge, since the planned application has to follow very different, dynamic daily and annual gradients of these parameters. In the following the plant performance is exemplarily presented for selected phases in the period of the 1st growth in 2018 (04.04.2018 to 27.05.2018). This evaluation phase was selected because it is characterized by heterogeneous environmental conditions as well as by a strong change of the plot surfaces. In order to be able to illustrate trends, the minute data from heating and fumigation were combined to daily values for evaluations over the entire period of the first growth. Statistical evaluations for this period are based on minute data. For the representation of daily courses of certain parameters, two test periods of three days each with completely different basic conditions were selected and the minute data were combined into hourly data (see Figure 2).

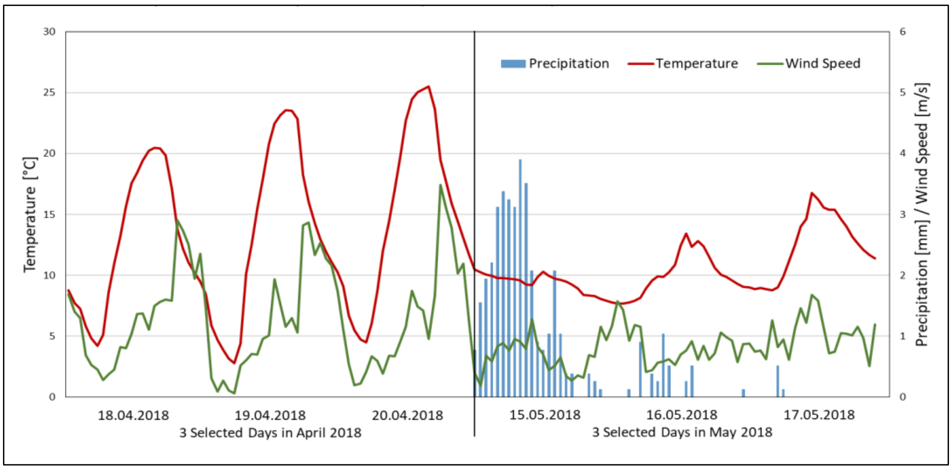

Figure 2: Weather conditions in two selected test periods in April and May 2018

Test period I (Figure 2, left) from April 18, 2018 to April 20, 2018 fell in the initial phase of the first growth. At this time the plants were in the phenological stage of shooting and the soil surface was not yet completely covered with vegetation. The three days were free of precipitation, sunny throughout and had above average temperatures. However, on these days there was relatively strong and persistent wind, which is of great relevance especially for the control of fumigation.

Test period II (Figure 2, right) in May (May 15, 2018 to May 17, 2018) is fundamentally different from that in April. It is a "bad weather phase" with precipitation, low sunshine duration and relatively low temperatures. However, the wind force was very low on these days. The plant stand was already fully developed and was in the phase of ear-/ panicle emergence. The two selected periods are compared, so that the differences can be seen very clearly.

Heating performance

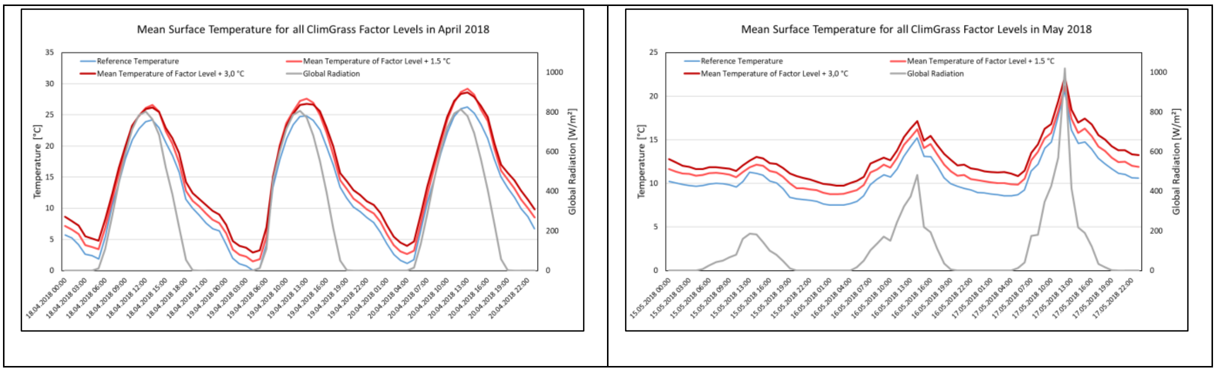

Figure 3: Course of global radiation and surface temperature for the temperature variants T0, T1 and T2 in the two three-day test periods

In test period I, the surface temperature curve shows three typical day cycles with a clear distinction between the cooler night phase and the warmer day phase with a temperature amplitude of up to almost 30 °C (Figure 3 left). In the test period 2, which is rich in precipitation, the three diurnal cycles for the surface temperature are quite different and have an amplitude of about 5 to max. 15 °C (Figure 3 right). In both test periods, the variants with temperature increase over long distances clearly stand out from the ambient reference temperature, whereby the differentiation is more pronounced at lower temperatures than at higher temperatures. At very high temperatures of more than 30 °C the infrared radiators used reach their technical limits and a further application of temperature is then no longer feasible. Related to the whole period of the 1st growth from 04.04.2018 to 27.05.2018, almost 75% of all collected measured values (on a minute basis) of the variant T1 were used for the performance analysis (control signal range from 0.1 to 9.9 within the total range of 0 to 10 volts). With respect to the target value of + 1.5°C, 96.8% of these measured values were within a range of ±10% around the target value. For the variant T2 with the target value of + 3°C, just under 70% of the measured values were included in the performance evaluation, whereby 96.5% of the measured values here were within ±10% of the target exposure value.

Fumigation performance

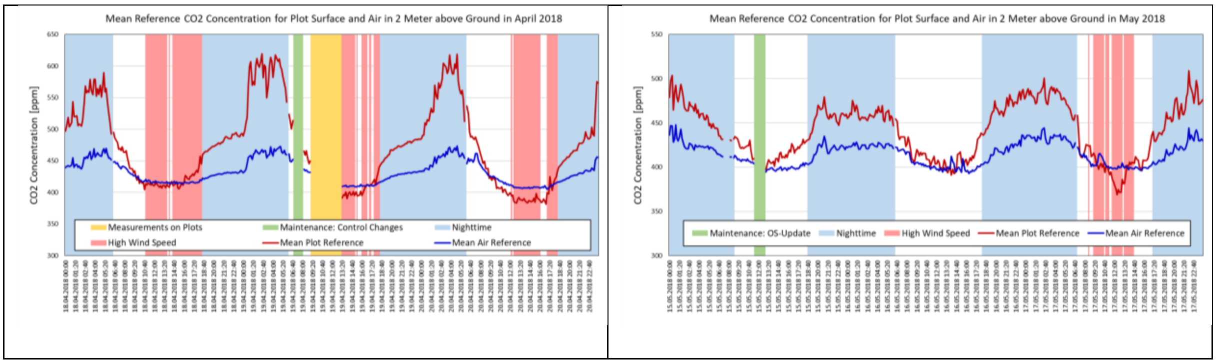

Figure 4: Course of the CO_2 concentration in the two test periods (reference CO_2-concentration in the atmosphere = blue, concentration in unaffected reference plots = red)

The atmospheric CO_2 concentration, measured at a height of 2 m, fluctuates between almost 400 and 470 ppm during the two test periods, with the higher values always occurring during the night hours and reflecting the increased respiration during this phase (blue curves). These measured values come from high-precision CO_2-sensors, which thus also provide a very good insight into the diurnal course of the atmospheric CO_2-concentration present at the Gumpenstein site. The CO_2-concentration measured near the ground on untreated reference plots shows a similar diurnal cycle, but with a much more pronounced amplitude (red curves). This underlines the much greater influence of CO_2 respiration activities by the plant stand near the ground. The convergence of the two measured values with increasing wind speed is also clearly visible, which is due to the resulting mixing and concentration equalization.

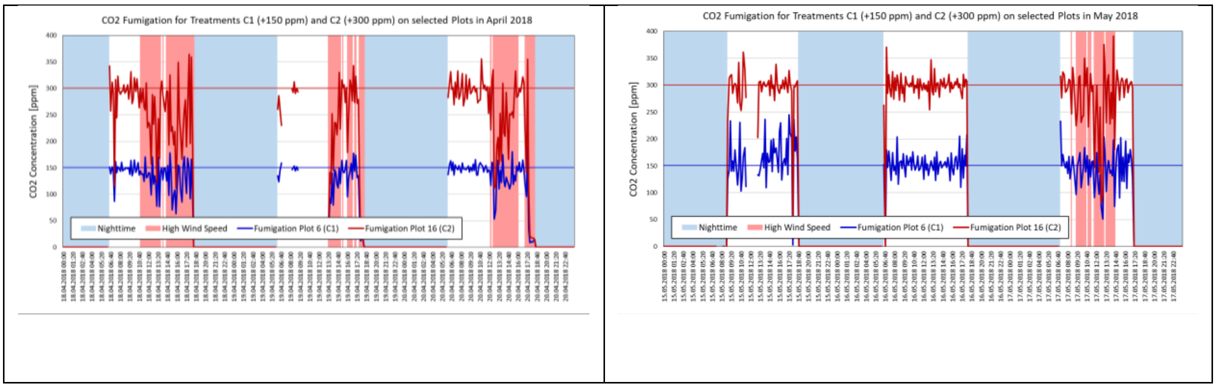

Figure 5: Course of the CO_2 impact for the fumigation variants C1 and C2 in the two three-day test periods

In both test periods, the influence of increased wind speeds can be seen with regard to the quality of the admission (areas highlighted in red), in which increased control activity at both fumigation levels leads to significantly higher fluctuations around the respective target value (Figure 5). The stronger fluctuations in CO_2 concentration compared to heating result from the sluggish reaction of the gas supply after re-opening resp. "overshooting" of the concentration after closing the valves.

Related to the whole period of the 1st growth from 04.04.2018 to 27.05.2018, 63,4 % of all measured values of variant C1 collected on a minute basis were used for the performance analysis (exclusion of measured values with wind or with CO_2 values higher than the ambient concentration + 450 ppm). With respect to the target value (+ 150 ppm), 79.6 % of these measured values were within a range of ±20 % around the target value. For the variant T2 with the target value + 300 ppm, 66.2 % of the measured values were used for the performance analysis. Here, the degree of target achievement for the range of ±20 % around the target value was 68.3 %.

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