Data from the Braunschweig FACE (free-air CO_2 enrichment) experiments on sugar beet at adequate and low levels of nitrogen supply

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Abstract: The objective of the present study was to investigate the effect of rising atmospheric CO_2 concentrations at different nitrogen supply on growth, yield and sugar content of sugar beet. Sugar beet was grown twice (2001, 2004) within a crop rotation at ambient and elevated atmospheric CO_2 concentration (375 and 550 ppm) fertilized with a high (126, 156 kg N ha^{-1}) or low level (63, 78 kg N ha^{-1}) of nitrogen supply. In the second year another cultivar was used to prevent infestation by rhizomania, which occurred on one half of the field plots at the end of the season of 2001. In 2004, shading was included as an additional treatment. Data set includes data on management, soil condition, weather, below and above ground growth (individual leaves, leaf area index, total biomass, beet yield and composition, water soluble carbohydrates, root biomass). Data can be used to validate the effect of elevated CO_2 concentration in sugar beet growth models.

Keywords: sugar beet, free air CO_2 enrichment, FACE, nitrogen fertilization, leaf growth, root growth, biomass, yield, beet composition

1 BACKGROUND: The rising atmospheric CO_2 concentration [CO2] is known to increase photosynthesis and growth and to decrease stomatal conductance and transpiration of C3 crops (Ainsworth and Long, 2005). In Europe existing studies on high [CO2] effects on C3 crops were mainly based on chamber studies (e.g. open-top chambers), which suffer from several limitations, which may prevent realistic estimates of the CO_2 effect. The free air CO_2 enrichment technique (FACE) leaves the environment of a crop nearly fully unperturbed. Therefore, a FACE experiment was carried out in Braunschweig, Germany, to investigate the effects of elevated [CO2] on a crop rotation at a high N level according to farmers´ practice and at a low N level. The rotation consisted of winter barley and ryegrass as a cover crop in the 1st year, sugar beet in the 2nd year and winter wheat in the 3rd year. The rotation cycle was repeated once resulting in a FACE experiment over six years from 1999 to 2005 (Weigel and Manderscheid, 2012). Plants were irrigated if needed to avoid interactions with drought.

Sugar beet was studied on the FACE field site in Braunschweig, Germany, in two years (2001, 2004) at ambient (371, 377 ppm) and elevated CO_2 (550, 549 ppm). CO_2 treatments were conducted at an adequate level of N fertilization (N100: 126, 156 kg N ha^{-1}) and at a low N level (N50: 63, 78 kg N ha^{-1}). In August of the 1st growing season about half of the experimental field was found to be infected by a viral disease. Therefore, another cultivar was used in 2004. Plants grown under FACE showed an acceleration of canopy senescence starting in August 2001. To test whether this is related to sink limitation of growth as previously found in a chamber experiment (Demmers-Derks et al., 1998) a shading treatment was included in the 2nd year.

Comprehensive measurements were performed on the soil compartment (soil moisture, soil microbial activities, soil fauna, root growth) and above ground compartment (leaf growth, biomass production and partitioning, tissue nitrogen concentration, water soluble carbohydrates, canopy CO_2 and water flux, canopy microclimate, beet yield and composition). Findings have been published in various Journals and have already been used by crop modelers (see papers listed in the REFERENCES).

2 METHODS: Sugar beet was part of a crop rotation, which was exposed to ambient and elevated [CO2] using a FACE facility under typical (N100) and 50% of typical nitrogen fertilization (N50). The crop rotation consisted of winter barley and ryegrass as cover crop in the 1st growing season, sugar beet in the 2nd and winter wheat in the 3rd growing season. The crop rotation started in autumn 1999 and was carried out twice. Accordingly, sugar beet was grown in 2001 and 2004. The selected crop rotation is typical for North Germany.

2.1 EXPERIMENTAL FIELD SITE. The experiments were conducted on a 22 ha field at the Johann Heinrich von Thuenen-Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries (formerly Federal Agricultural Research Centre, FAL), Braunschweig, South-East Lower Saxony, Germany (52°18' N, 10°26' E, 79 m a.s.l.). The soil is a Luvisol of a loamy sand texture (69% sand, 24% silt, 7% clay) in the plough horizon (0-30 cm). The profile has a depth of about 60 cm (--30 cm Ap, --15 cm Al, --15 cm Bt, >60--70 cm CII). The lower layers, in particular >70 cm, are characterized by a coarser soil texture (almost pure sand) and are structured by the succession of thin silt/clay layers. The plough layer has a pH of 6.5 and a mean organic carbon content of 1.4% and a total N content of approx. 0.1%. The drained upper (0.01 MPa soil water tension) and lower limits (1.5MPa water tension) of plant available volumetric soil water content were 23% and 5%, respectively. Thus, the soil has a volumetric plant available water content of ca. 18% in the plough layer, which decreases slightly with increasing soil depth.

2.2 CO_2 TREATMENTS: A circular free-air CO_2 enrichment (FACE) system of the Brookhaven National Laboratory design (Lewin et al., 1992) with experimental rings of 20 m in diameter was operated for the experiments. Treatments included two rings operated with blowers at ambient air CO_2 concentration (= BLOWER) and two rings equipped with blowers and air enriched with CO_2 (= FACE). The target CO_2 concentration in the plots was set to 550 ppm during daylight hours (i.e. daylight solar altitude θ >-0.833). At wind speeds > 6 m s^{-1} CO_2 enrichment was interrupted. For each crop cycle the FACE system was installed immediately after sowing and removed after final harvest. CO_2 treatments started shortly after emergence of the crops.

2.3 CROP CULTIVATION: Agricultural management measures of the total 22 ha field and the FACE plots, respectively, were carried out according to local farm practices and included plough tillage, mineral fertilization and pesticide applications for control of weeds and fungal infection. In 2001, the widely grown sugar beet cultivar Wiebke was used. However, in August 2001 half of the experimental field area was found to be infected by rhizomania. Therefore, in 2004 this cultivar was replaced by the resistant cultivar Impuls. Both cultivars were registered in Germany in 1998 and have similar sugar yield potential. In March the field was fertilized with macronutrients (K, Mg, P, S) based on soil nutrient analysis and subsequently ploughed and worked with a cultivator. Sugar beet was sown in east-west rows spaced 0.45 m with a seeding density of 11 plants m^{-2}.

2.4 NITROGEN FERTILIZATION: Each of the two control and FACE rings was divided in two semicircles, which were fertilized with nitrogen according to local farmers´ practice (N100) and with 50% of this level (N50), while supply of other nutrients was identical in both nitrogen treatments. At the end of winter the field was fertilized with macronutrients (K, Mg, P, S) based on soil nutrient analysis and subsequently ploughed and worked with a cultivator. Soil mineral nitrogen at spring time amounted to ca. 30 kg N ha^{-1} in 0-0.60 m depth. Nitrogen was added twice as ammonium nitrate-urea solution. In 2004 the total field was supplied with diammonium phosphate at a rate of 54 kg N ha^{-1}. N fertilizer added to the respective experimental area (N50/N100) amounted to 63/126 kg N ha^{-1} and to 78/156 kg N ha^{-1} in 2001 and 2004, respectively.

2.5 IRRIGATION: The field was irrigated with a linear irrigation system to avoid water limitations and resulting interactions with the CO_2 treatments by keeping the soil water content above 50% of maximum plant available soil water content. Accordingly, the whole field was irrigated with a total amount of 107 mm in 2001 and of 84 mm in 2004.

2.6 SHADING TREATMENT: The sink size of the storage root of sugar beet depends on the number of cambial rings most of which are developed until July. In order to reduce the source activity without a strong impact on sink size two subplots (1.5 m x 2.5 m) in each of the 8 semicircles were shaded from 15 July 2004 until final harvest. Final canopy height amounted 0.6 m and 0.7 m in the N50 and N100 treatment. Accordingly, shading was done by installation of nets at a height of about 0.7 m and 0.8 m in the N50 and N100 treatment, respectively. Shading nets reduced incident radiation to 51% as compared to the unshaded area.

2.7 MEASUREMENTS:
2.7.1 SOIL MOISTURE AND WEATHER: Soil water content was monitored by TDR probes installed at 25 and 45 cm depth, respectively, in each of the four semicircles with normal N fertilization. Volumetric soil water content was recorded approximately twice per week. Air temperature, global

radiation and precipitation measured at 2 m height nearby the experimental field site (<500 m) were provided by the German Weather Service.

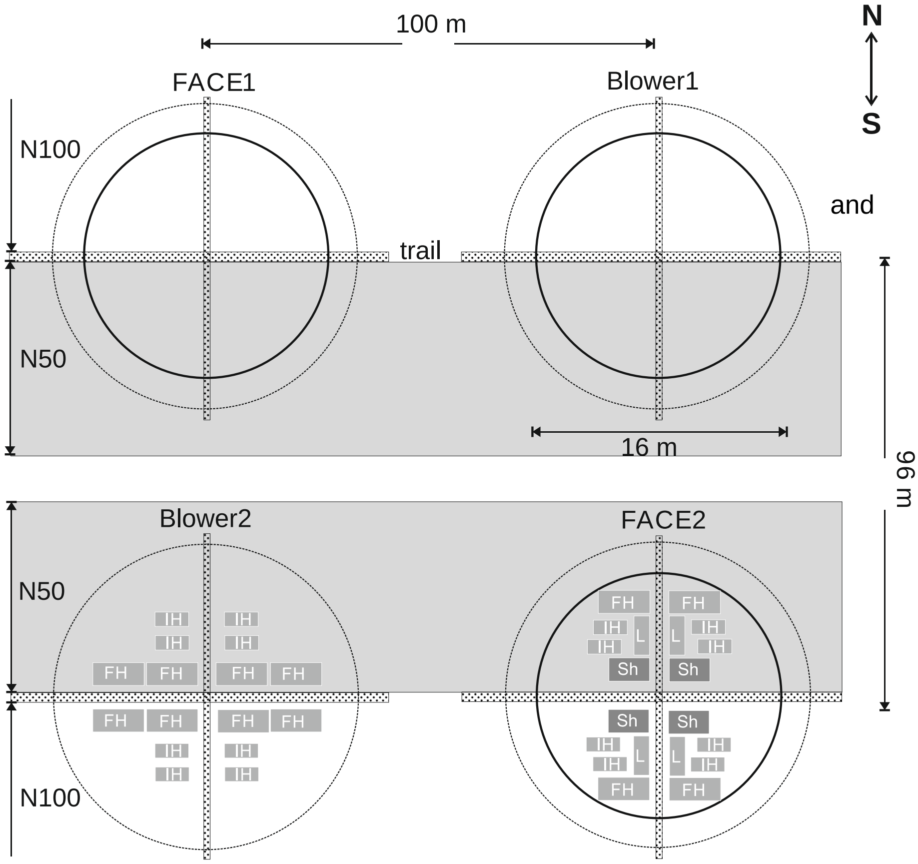

FIGURE 1: Spatial arrangement of the rings with ambient CO_2 (Blower1 & 2) and elevated CO_2 (FACE1 & 2) and the two levels of nitrogen supply. Plant material was harvested from an internal ring area of 16 m diameter. Distribution of the research activity zones within the ring in 2001 and 2004 is shown in Blower2 and FACE2, respectively.
FH: final harvest areas,
IH: areas for intermediate harvests,
L: area for leaf growth analysis,
Sh: area with shading net.

2.7.2 CROP DATA: Size and distribution of sampling areas for the various measurements is shown in Figure 1. Whole plant samples were taken at 3 dates from an area of 4-6 m^2 per semicircle. The major fraction (70-80%) was dried at 105°C and dry weight was determined. The remaining fraction was used for dry weight estimation of storage roots, petiolus, dead and green leaves and of green leaf area index. Nitrogen content of plant material was determined with a Leco TrueSpec CNS elemental analyzer after milling to a fine powder (1 mm). Milled powder of petiolus was used for measurement of water soluble carbohydrates. Beet composition was determined by the laboratory of the Institute of Sugar Beet Research, Göttingen, Germany. Values from one replicate blower and FACE ring are missing from the 2nd and 3rd sampling date since these areas were found to be infected by rhizomania from the beginning of August.
In 2004, timing of growth of individual leaves (11th, 16th, 26th, 31st) was analyzed on 8-12 plants per semicircle by repeated measurements of leaf length and width. Moreover, in 2004 fresh weight of the great sample of green leaves (70-80%) was measured followed by homogenization with a large cutter. Subsamples were used for determination of dry weight fresh weight ratio and of chlorophyll content. Data were used to calculate the amount of total chlorophyll per m^2 ground area.
Detailed descriptions of the measurement procedures are given by Manderscheid et al. (2010). Data on root growth included measurements of root dry weight, root length density and specific root length (Pacholski et al., 2005).

5 DATA FORMAT AND STRUCTURE

All data are in the EXCEL file „sugarbeet-FACE.xlsx“. This file contains 11 worksheets and their specific data are listed in Table 1.

ACKNOWLEDGEMENTS

The FACE apparatus was engineered by Brookhaven National Laboratory and we are grateful to Dr. George Hendrey, Mr. Keith Lewin, and Dr. John Nagy for their support. Technical assistance by the staff of the Institute of Agroecology of the former Federal Agricultural Research Centre (FAL), by the Agrometeorological Research Station of the German Weather Service at Braunschweig and by the staff of the experimental station of the former FAL is gratefully acknowledged. We are also indebted to

Bernd Kleikamp for root growth analysis and Peter Laab for leaf growth measurements. This project was financially supported by the Federal Ministry of Food and Agriculture.

Table 1

Worksheet name	**Content**
data files & abbreviations	Name of the data files, abbreviations and units
TRNO definition	Code and definition of the different treatments
soil properties	drained upper and lower limit of water content at different soil layers in 0-60 cm depth
weather2001	15-minute average weather data (temperature, radiation, humidity, wind speed, rainfall; measured at 2 m height, nearby the FACE field (<500 m)) for 2001
weather2004	15-minute average weather data (temperature, radiation, humidity, wind speed, rainfall; measured at 2 m height, nearby the FACE field (<500 m)) for 2004
manage	Management measures (ploughing, sowing, fertilization, pesticide application, irrigation, plant growth stage, time of CO2 enrichment)
soil moisture 2001a2004	Soil moisture content measured with TDR sensors, from 2001 and 2004
growth data 2001	Growth data of the 1st experimental year (above and below ground)
growth data 2004	Growth data of the 2nd experimental year (above and below ground)
sugar yield	Data of beet composition and sugar yield from both years (2001&2004)
leaf growth 2004	Data of individual leaf growth measured in 2004

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