INTERACTIVE EFFECT OF ELEVATED CO_2 CONCENTRATON, DROUGHT STRESS, NITROGEN NUTRITION AND UV RADIATION PHYSIOLOGY, YIELD AND GRAIN QUALITY OF WINTER WHEAT

WUTTHIDA RATTANAPICHAI[1], KAREL KLEM[1,2], PETRA RAJSNEROVA[2,3]
[1]*Department of Agrosystems and Bioclimatology, Faculty of Agronomy, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic*
[2]*Global Change Research Centre AS CR, v. v. i. Bělidla 986/4a, 603 00 Brno, Czech Republic*
[3]*Department of Landscape Engineering, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic*

Numerous experiments on winter wheat have demonstrated that elevated CO_2 concentration leads to increased CO_2 assimilation rates, higher accumulation carbohydrates, biomass production and yields. However, the interactive effects with other climate change related factors such drought stress or UV radiation, particularly with respect to grain quality, are still not well understood. Within the manipulation experiment in open top chambers (Domanínek, near Bystřice nad Pernštejnem) that allow simulation of elevated concentration of CO_2 (expected by the end of this century – 700 µmol.mol^{-1}), drought stress and exclusion of solar UV radiation, the interactive effects of these environmental drivers on winter wheat (variety Bohemia) together with nitrogen application were studied. Aboveground biomass at the time of harvest, grain yield, root area, grain quality and physiological parameters such as CO_2 assimilation rate were studied. The results showed that the elevation of CO_2 concentration have a positive effect on CO_2 assimilation rate, plant growth and grain yield. However, this stimulation effect was higher under higher nitrogen level and UV – exclusion. Elevated CO_2 concentration generally led to a decrease in grain protein content. Drought stress in interaction with CO_2 concentration had only minor effect on the grain yield and quality.

Keywords: winter wheat, elevated CO_2 concentration, drought stress, nitrogen nutrition, UV radiation, root area, protein content, CO_2 assimilation rate

INTRODUCTION

Atmospheric carbon dioxide concentration ([CO_2]) has increased about 30 % since pre-industrial times. Numerous experiments have demonstrated that in many plant high atmospheric [CO_2] leads to increases in photosynthetic rate, whole-plant growth and water use efficiency (WUE). Some experiments have found nutrient deficiency decreases in the protein concentration, (Conroy *et al.*, 1994). The effect of elevated [CO_2] on photosynthesis has been shown to enhance growth and yield of crop plants under suitable conditions (Reddy and Hodges, 2000). When nitrogen is high, elevated [CO_2] leads to a sustained stimulation of photosynthesis and growth (Geiger, et al., 1999).

When exposed to increased CO_2, roots have been observed to become more numerous, longer, thicker, and faster growing in crops (Chaudhuri et al., 1990). Branching and extension of roots under elevated [CO_2] may lead to altered root architecture and ability of roots to acquire water and nutrients from the soil profile with exploration of the soil volume. The underlying assumption that a larger proportion of dry matter produced under [CO_2] enrichment is preferentially allocated to roots and increased under limiting water and nutrient supply needs to be evaluated (Rogers, et al., 1992).

Effects of ultraviolet (UV) irradiation on biological matter became an important issue over the past few decades. Exposure to high UV-B radiation alters photosynthetic enzyme activities and disrupts PSII reaction centres (Iwanzik, at al., 1983). Many researchers have reported reduction in biomass accumulation due to UV-B exposure in crop (Kakani, et al., 2003). Exclusion of UV significantly increased the total chlorophyll, the efficiency of PS II (Fv/Fm), rate of photosynthesis and stomatal conductance. Moreover, exclusion of solar UV also enhanced root growth (Sharma and Guruprasad, 2012)

Drought is an important environmental constraint that limits the productivity of many crops and affects both quality and quantity of the yield (Boyer 1982). There was reported that high CO_2 concentration increased the total dry mass significantly, but its effect depended on the N levels and irrigation. In the well-watered treatment, elevated CO_2 increased total mass when N level was moderate to high but had no significant effect in the low N treatments. (Li, et al., 2003)

The purpose of this study was to investigate and compare the effect of CO_2 concentration, drought stress, nitrogen nutrition, UV radiation and their interaction on physiology, yield and grain quality of winter wheat.

MATERIALS AND METHODS

The experiment was conducted in experimental station Domanínek, near Bystřice nad Pernštejnem in Bohemian-Moravian highlands (Czech Republic, 49°521'N, 16°235'E, altitude 575 m a. s. l.). The soil type is modal cambisol, with geological bedrock weathered gneiss in depth 60-90 cm. Soil texture is sandy loam (45-60 % sand and up to 16 % clay) and pH(KCl) is between 4-5. This region is characterised as rain-fed area with mean annual precipitation 610 mm and mean annual temperature 7.2 °C. The experiment consists of 24 open-top chambers, which allows manipulation of [CO_2] and precipitation. UV radiation was excluded by using the non-transparent plastic roof. Winter wheat variety Bohemia with bread quality A was sown on 9th October 2013 in the chambers with density 4 MGS (millions of germinating seeds). Fumigation with elevated [CO_2] (EC; 700 µmol.mol^{-1}) started at the beginning of stem elongation (middle of May) and drought stress induction started at the end of stem elongation (end of May). The plots inside chamber were divided to two subplots and one of them fertilized with calcium nitrate in a dose 200 kgN.ha^{-1} at the growth stage end of tillering. The second subplot remained unfertilized with nitrogen. Each combination of factors was three times replicated.

The aboveground biomass was harvested manually at full ripening and weighted. This was followed by threshing of grain using a small plot harvester and calculated grain yield (t.ha^{-1}). The cleaned grain was used for analysis the protein content and starch content. The roots of four plants were dug out from the soil by excavation of soil around the root system in depth about 20 cm and gently washed them on 0.05 mm mesh sieve. Photos of roots taken using the digital camera were analysed by image processing software Image J.

RESULTS

The result showed that N application and elevated [CO_2] had significant effect (P<0.01) on aboveground biomass (Table 1). The treatment of N application increased aboveground biomass when compared to without N irrespective of the drought, [CO_2] and UV radiation (Figure 1). Nitrogen application increased aboveground biomass up to 96.8 %. High atmosphere [CO_2] increased aboveground biomass (16.12 %) when compared to the normal ambient [CO_2] especially when was treated with N application and UV exclusion which is consistent with the results of Li Kang, (2002) found that high CO_2 concentration increased the total dry mass significantly, but its effect depended on the N levels and irrigation. The interactions of drought x [CO_2] and drought x UV were significantly related to aboveground biomass (P < 0.05), moreover those of UV x N, UV x [CO_2] and N x [CO_2] interaction were also significantly with P < 0.01 (Table 1). Elevated [CO_2] could increase more aboveground biomass in adequate water condition than dry condition. The UV exclusion treatments, winter wheat which were grown in elevated [CO_2] condition had higher aboveground biomass than ambient [CO_2] probably because exclusion of UV increased rate of photosynthesis and CO_2 fixation (Sharma and Guruprasad, 2014). Interactive effect of adequate water and exclusion slightly increased aboveground biomass. On the other hand, interactive effect of drought stress and non-exclusion of UV slightly decreased aboveground biomass. Adequate water and N, UV exclusion and elevated [CO_2] interaction gave the highest aboveground biomass up to 34.27 $t.m^{-2}$.

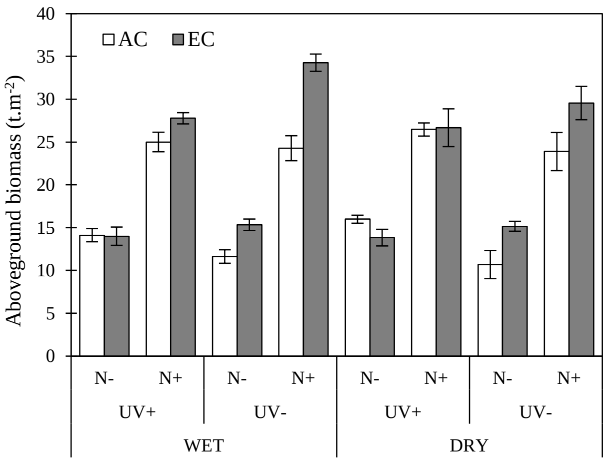

Figure 1. Effects of elevated CO_2 concentration, drought stress, nitrogen nutrition and UV radiation on aboveground biomass ($t.m^{-2}$) of winter wheat. WET (ambient precipitation), DRY (drought stress), AC (ambient CO_2 concentration; 390 $\mu mol.mol^{-1}$), EC (elevated CO_2 concentration; 700 $\mu mol.mol^{-1}$), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 $kg.ha^{-1}$), UV- (UV exclusion), UV+ (non UV exclusion). Columns represent means±S.E. (n = 3).

N application and elevated [CO_2] had significant effect (P<0.01) on grain yield (Table 1). But there were no significant effect of UV radiation and drought stress on grain yield. N application and elevated [CO_2] could increase grain yield of winter wheat when compared to without N application and ambient [CO_2] by 91.8 % and 25.6 % respectively (Fig. 2). There were interactive effect of UV x [CO_2] and N x [CO_2] on grain yield (P<0.01). The increasing of grain yield by elevated [CO_2] under exclusion of UV had higher efficiency than non-UV exclusion. Elevated [CO_2] increased grain yield especially when was treated with N. N supply strongly interact with elevated [CO_2] effect influencing plant metabolism and grain yield (Erbs, et al., 2010). When N nutrition is high, elevated [CO_2] leads to a sustained stimulation of photosynthesis and growth (Geiger, et al., 1999). Interactive effect of adequate water, N application, UV exclusion and elevated [CO_2] gave the highest grain yield of winter wheat.

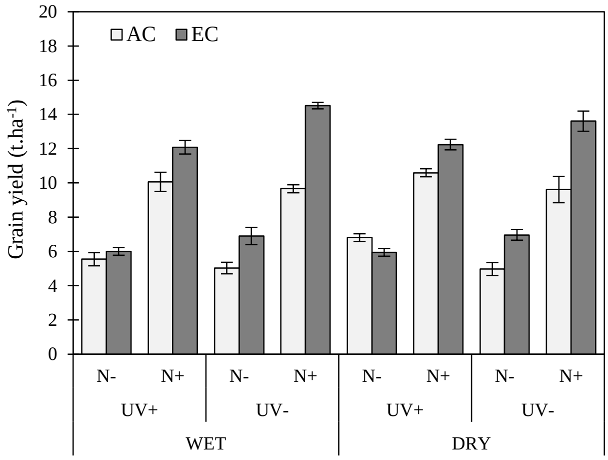

Figure 2. Effects of elevated CO_2 concentration, drought stress, nitrogen nutrition and UV radiation on grain yield ($t.ha^{-1}$) of winter wheat. WET (ambient precipitation ; (a)), DRY (drought stress; (b)), AC (ambient CO_2 concentration; 390 $\mu mol.mol^{-1}$), EC (elevated CO_2 concentration; 700 $\mu mol.mol^{-1}$), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 $kg.ha^{-1}$), UV- (UV exclusion), UV+ (non UV exclusion). Columns represent means±S.E. (n = 3).

Drought stress and N application had significant effect (P<0.01) on root area (Fig. 3). Adequate water and N increased root area by 9.48 % and 28.8 % respectively. The interactions of drought x N, UV x N, UV x [CO_2] and N x [CO_2] were significantly related to root area with P < 0.01 (Table 1). The increasing of root ares by N application under drought stress had higher efficiency than adequate water condition. N application could increase root area especially when was treated with exclusion of UV or elevated [CO_2]. However UV exclusion together with elevated [CO_2] could increase root area of winter wheat. Moreover in dry condition, interactive of exclusion of UV, N application, and elevated [CO_2] gave the highest root area of winter wheat. There were interaction effect of drought x UV x N and drought x UV x CO_2 on root area (P<0.01).

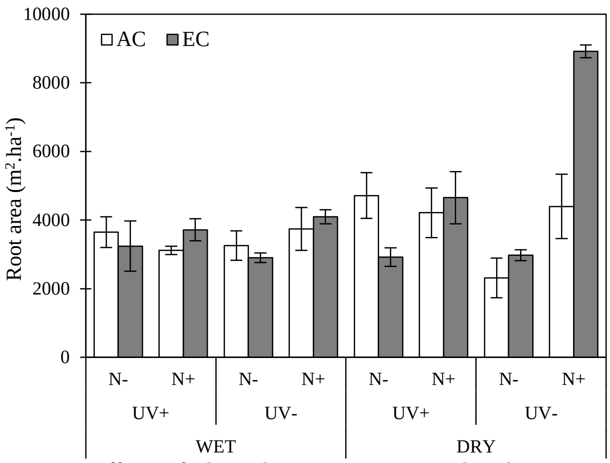

Figure 3. Effects of elevated CO_2 concentration, drought stress,

nitrogen nutrition and UV radiation on root area ($m^2.ha^{-1}$) of winter wheat. WET (ambient precipitation), DRY (drought stress), AC (ambient CO_2 concentration; 390 µmol.mol^{-1}), EC (elevated CO_2 concentration;
700 µmol.mol^{-1}), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 kg.ha^{-1}), UV- (UV exclusion), UV+ (non UV exclusion). Columns represent means±S.E. (n = 3).

Rogers et al. (1994) have shown that root dry weight increased under CO_2 enrichment and with no limitations of water and nutrients. Root systems of crops grown in CO_2 enriched environments are often more branched, especially at shallower soil depths (Rogers et al., 1992).

N application and elevated [CO_2] had significant effect ($P<0.01$) on protein content (Fig. 4). N application increased protein content by 26.85 % which is consistent with the results of Gokkus and Koc (1996) indicated that Protein content were increased by applied N fertilizer, while root/shoot mass ratio decreased. Elevated [CO_2] decreased protein content by 6.24 %. Moreover inadequate water condition decreased 4 % of protein content. The interactions of drought x UV x [CO_2] were significantly related to grain quality ($P < 0.01$).

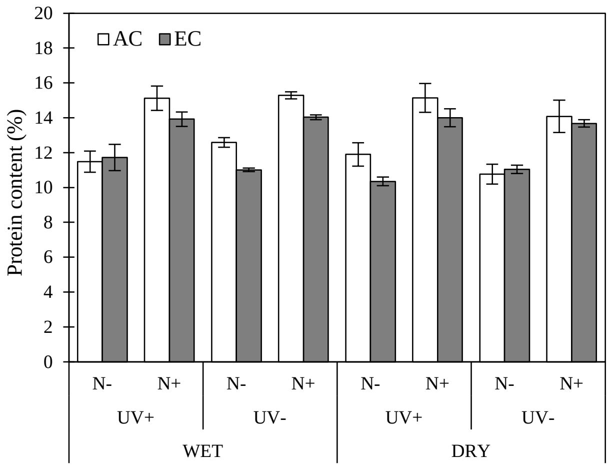

Figure 4. Effects of elevated CO_2 concentration, drought stress, nitrogen nutrition and UV radiation on protein content (%) of winter wheat. WET (ambient precipitation), DRY (drought stress), AC (ambient CO_2 concentration; 390 µmol.mol^{-1}), EC (elevated CO_2 concentration; 700 µmol.mol^{-1}), N- (unfertilized with nitrogen), N+ (fertilized with nitrogen 200 kg.ha^{-1}), UV- (UV exclusion), UV+ (non UV exclusion). Columns represent means±S.E. (n = 3).

Table 1. The Significant from ANOVA test. Significant values was indicated: **, $P<0.01$; *, $P<0.05$

Source	Abovegroun biomass ($t.m^{-2}$)	Yield grain ($t.ha^{-1}$)	RootArea ($m2.ha^{-1}$)	Protein content (%)
DROUGHT	ns	ns	**	*
UV	ns	ns	ns	ns
N	**	**	**	**
CO_2	**	**	ns	**
DROUGHT * UV	*	ns	ns	ns
DROUGHT * N	ns	ns	**	ns
DROUGHT * CO_2	*	ns	ns	ns
UV * N	**	ns	**	ns
UV * CO_2	**	**	**	ns
N * CO_2	**	**	**	ns
DROUGHT * UV * N	ns	ns	ns	ns
DROUGHT * UV * CO_2	ns	ns	ns	**
DROUGHT * N * CO_2	ns	ns	ns	ns
UV * N * CO_2	ns	ns	ns	ns
DROUGHT * UV * N * CO_2	ns	ns	ns	ns
REP	ns	ns	ns	**
CV.	7.96	7.57	20.39	5.22

CONCLUSION

Elevated [CO_2] stimulates photosynthesis and, consequently, leads to increased production of aboveground biomass, grain yield and also root area. The effect of elevated [CO_2] is more pronounced if apply with N fertilizer and also under the effect of UV exclusion probably due to high level of nitrogen and UV exclusion increased the stimulatory effect of CO_2 on growth of winter wheat. Moreover, elevated [CO_2] and UV exclusion stimulate more yield production in adequate water condition. Elevated [CO_2] and drought stress leads to a decrease in grain protein content. Adequate water and nitrogen can increased root area.

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