Enhanced UV-B Effects on Wheat under Different Temperature, Solar Light and Soil Moisture

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Abstract

Ultraviolet radiation-B (UV-B) will increase in the future due to the Ozone depletion; global climatic factors, such as temperature, precipitation, evapotranspiration, soil moisture and CO_2 content, are changing because of the increase of greenhouse emission and the destruction of ecosystems. Both of them have effects on crop production. Many studies have assessed the effects of enhanced UV-B on crops and impacts of global climatic change on crops separately. However, when UV-B effects were discussed, other environmental factors were generally neglected. It is well-known that crops in nature are seldom affected by only a single stress factor, such as UV-B radiation. The impacts of elevated UV-B radiation can be greatly increased or decreased by other environmental factors. In this paper, through field and plant growth chambers experiments, interactional effects of enhanced UV-B radiation with other environmental factors including solar visible light, temperature and soil moisture content were investigated on wheat fields. The experimental results show that increased UV-B can restrain growth and development of wheat, which leads to shortening plant height, reducing leaf area, slowing physiological activity and decreasing biomass and yield of wheat. The response of wheat to enhanced UV-B varied with UV-B intensity and climatic conditions. While in stress, some of the climatic factors cause screening or weaken effects of UV-B on wheat to some extent.

Introduction

Ceaselessly depleting stratospheric O_3 and Ozone depth will result in increasing ultraviolet radiation(UV-B) at the earth's surface because of the intensifying of atmospheric pollution. The ozone concentrations in the mid-latitudes (35-60° N and 35-60° S) are 3-6% lower than pre-1980 values (UNEP, 2002) and the UV-B amount has increased by 6-14% since 1980s (UNEP, 2002; Kakani et al., 2003). Following *Scientific Assessment of Ozone Depletion: 1998* (WMO, 1999) and *Scientific Assessment of Ozone Depletion: 2002* (WMO, UNEP http://www.wmo.ch/web/arep/ozone.html), ozone remains depleted in the mid-latitudes of both hemispheres and hence surface UV radiation will be increased.

The green house gases in the atmosphere, such as CO_2 and methane, have increased steadily during the last few decades， leading to global climatic changes， in terms of temperature rise and precipitation fluctuation, evaportranspiration increase, and agricultural drought intensification. (IPCC, 2001a, b). According to a prediction, atmospheric CO_2 concentrations will double and the temperature will increase by 5.5° C by the end of the current century (Houghton et al., 2001).

Many research results have revealed that excessive UV-B has direct effects on crops. These researches showed that enhanced UV-B radiation can influence the growth, development, morphology, physiological activities, biomass, yield and quality of most plants on (Al-Oudat et al., 1998; Caldwell et al.,1998; Deckmyn et al., 1998; Huttunen et al., 1998; Correia et al., 1999; He et al., 2002; Lingakumar et al.,1999; Pinto et al., 1999; Li et al., 2000). A substantial number of studies have been conducted to evaluate the potential consequences of an increase in UV-B radiation on many plants (Krupa and Kickert, 1989), but most of them only considered the direct influence of UV-B on crops，instead of taking into consideration of the joint roles of UV-B enhancement and changes of other environmental conditions such as solar light intensity， temperature and moisture.

Increased atmospheric CO_2 concentration will have both direct and indirect effects on crop production. Direct impacts are to stimulate photosynthesis and improve the water use efficiency of crops (Ittersum et al*,* 2003), while the indirect effects on crops are through climate changes induced by elevated CO_2 concentration (Alig et al., 2002). Many studies have assessed both direct and indirect effects of increased CO_2 on crop production (IPCC, 2001a). The general conclusion of these raised showed the specter of possible deleterious effects of climate change on agricultural productivity (Alig et al., 2002). The impacts of enhanced UV-B on crops were not, especially, ignored when effects of the future global climatic changes on crops were analyzed.

Because lack of comprehensive assessment of interactional effects of enhanced UV-B radiation and other climatic factor changes, such as temperature increase, precipitation reduction, we have not had knowledge about general impacts of them on crops when they influence crops at the same time. Our hypothesis is that each effect of all factors will be cumulative. Based on analysis of UV-B effects on wheat, this paper probes into complicated impact of joint action between increased UV-B and changes of such ambient factors as light， temperature and water on wheat growth.

Materials and Methods

The experiments were conducted on a field at the Agrometeorological Experimental Research Station ($31^0$14'N, $118^0$42'E) of Nanjing Institute of Meteorology during 1996-2000. A small portion of the experiment was done in PGW-36 Plant Growth Chambers which were made in Canada. The experimental species were winter wheat variety NM-3, the most commonly grown crop variety cultivar in Nanjing region, which was provided by Jiangsu Academy of Agricultural Sciences. Wheat seeds were sown on November 30 in each year. Harvest was on May 30 every year.

The seeds were planted in rows spaced at 30 cm apart at a seeding density of 60 seeds per meter. The experiments were in 12 plots with the area of 3 m by 4 m in each plot. Four replications were performed for each crop. Six border protective rows were sown around each plot in order to minimize marginal (border) effects. These agronomic practices were those conventionally used by local farmers.

The experiments were divided into two groups, normal water supply and lack of water supply. After germination of the wheat, the supply of UV-radiation in each group was started. The UV-B treatments in every group experiments fall into four levels, with natural UV-B irradiance denoted as CK, addition of three UV-B lights denoted as T_1, T_2 and T_3, respectively, which are equivalent to 3.0, 5.8 and 11.4% increase, in order, of UV-B intensity at Nanjing and its vicinity. Artificial UV-B treatments were supplied by broadband, "Black-light" lamps with the spectral range of 280 – 400 nm. The CK treatment also had broadband lamps overhead, but the UV-B irradiance was filtered by 0.13 mm thick polyester (spectrally equivalent to Mylar Type S) plastic films that absorbed essentially all radiation below 320 nm. The Koadcel TA 401 0.13-mm-thick polyester plastic films were used to exclude the portion of UV-A (wavelength > 320 nm) and were changed weekly to ensure uniformity of UV-B transmission. Lamps were fitted with 50mm-wide mini-reflectors and manually adjusted for time and height control. Total daily photosynthetic active radiation (400 – 700 nm) under the lamps was about 90% of that above the lamps. Supplemental irradiation was provided daily at a constant rate during the day for 9 h centered around the solar noon. Therefore, plants beneath these lamps received supplemental doses in addition to ambient levels of UV-B radiation under the supplemental UV-B treatment. The height of the lamps above the plants was adjusted weekly to maintain constant lamp to plant distances as the plants grew.
In Nanjing, the water that growing wheat needs mainly comes from precipitation. The group lacking of water supply were set by covering suspended plastic film above plots when it was raining during experimental periods.

At a 4- and a 5-day interval, conventional observations were done of the number of tillers, plant height, leaf length and width, dry weights of the wheat differing parts during the growth and development, and also of head length, number of kernel per head and the weight of 1000 grains after harvesting.

During heading period, pot-planted wheat plants were moved into plant growth chamber. The different light intensities at same temperature or different temperatures under same light intensity were set up, and net photosynthesis and transpiration have been measured, using Li－6200 portable photosynthesis system made in American Li－cor company, under different temperature and solar light inside plant growth chambers or at fields.

The averages of 5 randomly selected plants were used for statistical analysis, using Paired

Samples *t*-test with statistical software of SPSS. The significance of the differences between treatments is presented as a comparison between UV-B enhanced treatment (T) and control treatment (CK), with ** and * represent very significance ($P<0.01$) and significance ($P<0.05$) respectively.

Results and Analysis

Effects of increased UV-B upon wheat, when other environmental factors are normal

Table 1 presents experimental results concerning effects of increased UV-B upon wheat, when other climate conditions are in normal. The experimental results indicate that the intensified UV-B radiance affects the crop in many aspects, with the bigger increase in UV-B irradiance leading to greater effect on the experimental wheat.

Table 1. Effect of increased UV-B upon wheat with other climate conditions being normal.

	CK	T_1	T_2	T_3
Plant height(cm)	70.5(100)	65.9(93.5)**	64.9(92.1)*	63.5(90.1)*
Leaf area(m^2)	0.3429(100)	0.3369(98.2)**	0.3285(95.8)*	0.3169(92.4)**
Photosynthetic rate (νmol • m^{-2} • s^{-1})	8.804(100)	7.231(82.0)*	6.447(73.5)	5.235(59.4)
Stoma conductivity(cm • m^{-2})	1.999(100)	1.624(81.24)	1.547(77.4)*	1.376(68.8)*
Transpiration rate (mmol • m^{-2} • s^{-1})	0.0127(100)	0.0114(89.8)*	0.0108(85.0)*	0.0102(80.3)
Biomass[a](g)	26.55(100)	23.55(88.7)**	21.75(85.9)**	20.21(76.1)*
Grain weight per head[a](g)	1.85(100)	1.66(89.7)**	1.37(74.1)*	1.31(70.8)*
Number of grain per head[a]	55(100)	49(89.1)*	42(76.4)	40(72.7)*

Note：[a]are data in harvest, the others in shooting.
( ) is the ratios of T_1 through T_3 to CK.

Increased UV-B stops the crop from full growth in such a way that the stronger the irradiance, the shorter the height, with T_3-given height being 90.1% of the CK case. The increased UV-B hinders leaf from full growth, with T_3 leaf area diminished by 8% compared to CK case, thus showing a remarkably poor growth.

The increased UV-B radiation affects the wheat physiology, thereby reducing markedly photosynthesis (declined by 40.6% in T_3 compared to CK case) and, to less extent, transpiration (19.7% in T_3 versus CK), which indicates that water usage efficiency (WUE) is decreased with the irradiance available. Therefore, it suggests that water consumption would increase in the future climate with UV-B to be enhanced. In that case wheat stomatal resistance would increase and stomatal conductance of leaf would weaken, with 31.2% drop as calculated for T_3 case, which does not favor transpiration and photosynthesis.

Increased UV-B has its varying-degree impacts on the photosynthesis and transpiration, indicating that it is detrimental to both the factors not only in stomatal behaviors but in ways such as reducing the vigor of wheat in its root system. Enhanced UV-B deprives vitality of the response center of plants to light system II, suppresses the transmission of electronics related to the system II, diminishes circular photophosphorylation separating the coupling, decreases the vigor of RUBP carboxylase and damages the membrane of quasi cysts.

Increased UV-B is unfavorable for the morphology and physiology of wheat, as shown in the reduction in photosynthetic area of the leaf and in photosynthetic efficiency, which causes a drop in the biomass and yields. Under the increased UV-B irradiance the weight of the dry substance is decreased; biomass declines from 11% to 24% and the drop occurs, to varying extent, to the number and weight of grains per wheat head. Taking T_3 as an example, the weight and number diminish by 29.2 and 27.3%, respectively.

As far as we know, some studies made such experiments under artificial control and higher UV-B irradiance with 20-80% increase compared to natural intensity. In contrast, our experiments are performed in cases of CK (natural UV-B irradiance), T_1 to T_3 with small amounts higher than that of the CK case but nevertheless these show noticeable effects on the growth/development, physiological activities and yield formation of the crop.

Effect of increased UV-B upon wheat under some unfavorable climate conditions

As indicated by a lot of researchers, future climate would greatly differ, characterized by steady augmentation of greenhouse gases like CO_2 responsible for the rise of temperature and redistribution in rainfall on a global basis, with more in some places and less in others, leading to agricultural drought in the latter. As a consequence, we have to allow for the interactions between increased UV-B and changed climate factors to occur in investigating increased UV-B impacts.

Yields of plants depend upon photosynthesis, as expressed by “yield = photosynthetic efficiency×photosynthetic area×photosynthetic time”, so that we will explore the photosynthetic effect from its impact on development and yield of the growing crop.

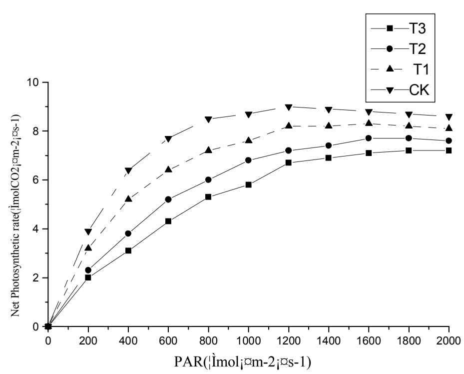

Fig. 1 Light-photosynthesis curves for wheat leaves in a range of UV-B levels (data taken in the heading stage under control conditions, temperature at 25 C°)

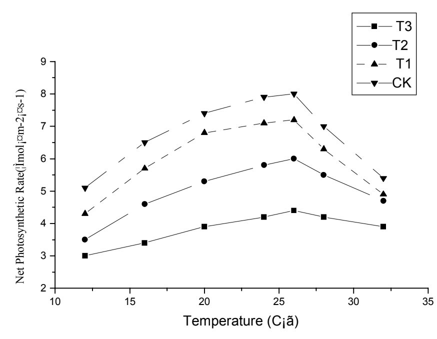

Fig.2 As in Fig. 1 but for photosynthesis temperature curves for wheat (data taken in the heading stage under control conditions, PAR was about $1000\mu mol\cdot m^{-2}\cdot s^{-1}$)

The increased UV-B producing impacts on photosynthesis and growth and development varies according to the difference in the intensity of visible light and air temperature as climate factors (Figs.1 and 2, respectively), where we notice that as visible light (PAR) is enhanced in strength the densities shown on the curves for the experiments T_1 to T_3 display a "close" to "apart" to "close" form, indicating that the increased UV-B suppression of photosynthesis exhibits a "weak-strong-weak" pattern. At the strength of 400-1000μ mol m^{-2} $s^{-1}$of visible light the effect of enhanced UV-B is the strongest. Visible light (PAR) radiation can have strong ameliorating impacts on response of plants to UV-B (caldwell et al., 1998), so the response of wheat to enhanced UV-B will be weaken when solar visible light is stronger. In view of our field and plant chamber experiments, high intensity of visible light (PAR), although able to cure the crop's injuries from increased UV-B, is accompanied by still stronger UV-B irradiance, resulting in reinforced negative impacts on photosynthesis of wheat.

At the same air temperature, net photosynthetic rate of wheat is reduced as UV-B is increased. Within the bound of the optimal temperatures (20-28^{0}C) the increased UV-B exerts maximum checking on the photosynthesis, and beyond the temperature range (especially higher temperature) the UV-B checking on the physiology is decreased. Photosynthesis serves as a foundation of growth and yield, which leads us to believe that increased visible light, too high and too low temperatures will alter the increased UV-B checking on wheat growth.

Table 2 Effect of enhanced UV-B on degradation of chloroplast of wheat

Treatment	Relative degradation of chloroplast（%）	
	6 days	12days
Sunlight（L）	86.3	60.5
Sunlight+UV-B（L+UV）	51.0	42.2
Darkness（D）	38.3	22.0
Darkness+UV-B（D+UV）	35.0	10.2

From the above analysis we see that there really exists light reactivation that is derived from our study on dynamic degradation of the chloroplast of wheat under increased UV-B (Table 2) where the degradation is accelerated as the irradiance is strengthened, and loss of chloroplast due to the increased irradiance can be speeded up in the dark but weakened in broad sunshine, of which the latter has been confirmed, suggesting that sunshine plays a role in the recovery of the UV-B made injuries.

Table 3 Effect of increased UV-B upon wheat with lack of water

	CK	T_1	T_2	T_3
Plant height(cm)	57.5(100)	55.1(96.7)*	54.9(96.3)*	63.5(94.7)**
Leaf area (m^2)	0.309(100)	0.307(94.4)**	0.302(97.7)*	0.3169(95.6)**
Photosynthetic rate (νmol •m^{-2} •s^{-1})	6.694(100)	5.630(94.1)*	5.042(75.3)*	5.235(63.1)
Stoma conductivity(cm • m^{-2})	1.756(100)	1.592(90.4)	1.475(84.0)*	1.376(79.8)**
Transpiration rate (mmol •m^{-2} •s^{-1})	0.0104(100)	0.0097(93.3)	0.0092(88.5)	0.0102(84.6)*
Biomass ^{a}(g)	22.567(100)	20.83(92.3)**	20.13(89.2)**	20.21(79.3)**

Grain weight per head[a](g)	1.50(100)	1.40(93.3)*	1.23(93.3)*	1.31(80.0)**
Number of grain per head[a]	48(100)	45(93.8)*	41(85.4)	40(81.3)

Table 3 shows that agricultural drought leads to the screening of UV-B checking on wheat growth, i.e., injuries from the irradiance are mitigated when wheat lacks water. In contrast, when soil water is sufficient/deficient a 9.9%/5.3% shortage of plant height is measured in T_3 as against CK and similar effect happens on physiological activities under increased UV-B in a dry plot. Compared to the CK case, in the sufficiently wet field T_3-given drops by 40.6%, for photosynthetic rate, by 31.2% for stomatal conductance and by 19.7% for transpiration, while in an insufficiently wet plot the corresponding drops are 36.9%, 20.7% and 15.4% respectively for those variables. Increased UV-B effects are reduced on the strength of water deficit upon the biological and economic yields.

The above results indicate that increased UV-B, higher temperature and water deficit are all detrimental factors to wheat. However, their combination does not enhance but weaken the total effects.

Also, we come to a conclusion that other environmental conditions (e.g., climate) than UV-B irradiance in the ecosystem are constantly changing. When the factors of light, heat and water are appropriate, increased UV-B exerts noticeably unfavorable influence, which is, however, weakened when they are detrimental to growth.

We can assume that in decades of years to come the combination of environmental factors will mutually weaken the role of related stress elements and, on the other hand, the rise of CO_2 content, for example, would favor the intensification of wheat photosynthetic rate, thereby reducing the injuries done to the crop by increased UV-B and other unfavorable factors. As a result, effect of future increased irradiance on wheat is a complex problem, which requires quantitative research into intensified UV-B irradiance and environmental factors with their interactions.

Discussion

Atmospheric temperature increase, water deficit and UV-B enhancement provide unfavorable impacts on wheat growth. As stated earlier, the unfavorable impacts, when combined, do not mean their summation but antagonism, leading to the joint effects being weaker than those of respective factors acting together.

$$y > y_0 e^{\cdot kx} \qquad (1)$$

Where y is the biomass or yield of wheat under exposure to UV-B, y_0 is the biomass or yield of wheat under controlling condition (CK), x is the intensity of UV-B radiation, k is the attenuation coefficient, which can indicate variation amount of each index with increase of UV-B.

Based on the experimental results (zheng et al., 1996), Eq.(1) is employed to deal with increased UV-B on wheats, but it is valid only for appropriate sunshine, air temperature and water content. As we know that the climatic is changing in future, some corrections of it are required.

$$y > y_0 e^{\cdot\ kx} \neg f(w) \neg f(T) \quad (2)$$

where $f(w)$ represents the function for water correction with $f(w)$ = 1 and $f(w)$ <1 for appropriate and deficient water content, respectively and $f(T)$ is the function for temperature reduction, with $f(T)$<1 and $f(T)$=1 for inappropriate and appropriate temperature, respectively, and the correction coefficient is found from

$$f(T) > \sum t_i / T \quad (3)$$

wherein $0<f(T)\leq 1$ and $f(T) = 1$ at $t = T_0$ for optimal temperature and t_i denotes physiological temperature during the *i–th* growth/development period calculated from actual environmental temperature by means of stepwise calculation of the parabolic response to environmental temperature during growth, taking the form

$$t_i > \begin{cases} 0 & \text{when } (t \times T_m \text{ or } t / \ T_n) \\ t & \text{when } (T_n = t = T_2) \\ t_2 \ .\ (t \ .\ T_2) & \text{when } (T_2 / \ t = T_m) \end{cases} \quad (4)$$

where t stands for actual environment temperature, T_n/T_m for minimum/maximum temperature of growth (its tolerance) and t_i/t_2 for the lowest/highest limit of most favorable temperature for photosynthesis.

T of (4.16) is found through

$$T > \begin{cases} T_1 & \text{when } (T_n / \ t / \ T_1) \\ t_i & \text{when } (T_1 = t / \ T_2) \\ T_2 & \text{when } (T_2 = t = T_m) \end{cases} \quad (5)$$

Correction of field water is based on

$$f(w) > \begin{cases} (1 \ .\ c) R_i / E_{c_i} & 0 = (1 \ .\ c) R_i = E_{c_i} \\ E_{c_i} / (1 \ .\ c) R_i & (1 \ .\ c) R_i \times E_{c_i} \end{cases} \quad (6)$$

in which $0 < f(w) \leq 1$, R denotes rainfall, c the runoff coefficient, i the growth/development stage, and E_c the actual evapotranspiration of crop that is in the form

$$E_c > K_c \propto E_0 \quad (7)$$

where K_c is the coefficient for conversion between actual and potential evapotranspirations and E denotes the in-field potential evapotranspiration from Penmen's method in the form

$$E_0 > \frac{\mathrm{E} \propto R_n \ ,\ \eta E_a}{\mathrm{E} \ ,\ \eta} \quad (8)$$

in which R represents the surface net radiation, Δ the slope of a saturation vapor pressure – temperature curve, γ the constant of humidity and E_a the index of dryness, with E = f (*u, e,e*) having its empirical model of fitting.

From (2) we are allowed to calculate the increased UV-B effects upon wheat in future climate warming and rainfall redistribution.

Climate change is a phenomenon in which the uncertainty of the components (CO2, temperature and precipitation) varies, and interactive impact of enhanced UV-B and climatic change on crops is complicated. We used simulation experiment and calculating methods to analyzed jointing response of wheat to both increased UV-B and climate change.

It is an attempt to assess interactional effects of enhanced UV-B radiation with change of other environmental factors. This work started just now, which a lot of work needs to be done.

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