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Simulated dust storm effect on dry mass, chlorophylls *a*, *b* and chlorophyll fluorescence of C_3 (*Triticum aestivum* L.) and C_4 (*Zea mays* L.) plants

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Abstract. *Triticum aestivum and Zea mays* were exposed to a gradient of dust concentrations 0.5, 1 and 1.5 g/m^3 in a dust chamber simulated by a dust generator. Results of this experiment indicate that biomass and chlorophyll content of shoots are negatively correlated with the intensity of dust exposure. Also, the amounts of reduction in productivity and photosynthetic capacity in *T. aestivum* were higher than to *Z. mays*. Exposure of *T. aestivum* to 0.5, 1 and 1.5 g/m^3 of dust compared with control have caused 4%, 37% and 54% decline in shoot biomass (ANOVA, $p \leq 0.05$) and exposure of *Z. mays* to dust concentration caused 2%, 14% and 24% reduction in treatments compare to control. Also, we showed that photosynthesis factors yield (ΔF/Fm´), electron transport rate (ETR) and potential yield (Fv/Fm) were affected by increasing the dust concentrations. Photosynthesis yield in *T. aestivum* reduced 5%, 25% and 32% in 0.5, 1 and 1.5 g/m^3 of dust concentration respectively. Exposure of *Z. mays* to dust has caused a significant reduction in ΔF/Fm´ of 8%, 16% and 26% for the dust exposures. At the same time a reduction of 20%, 33%, and 47% in the treatments is observed for ETR in *T. aestivum* and 12%, 22% and 32% in *Z. mays*. Current exposure to dust has also caused a reduction in Fv/Fm as much as 3%, 7%, 16% and 2%, 7%, 11% in *T. aestivum* and *Z. mays* respectively.

Key words: dust chamber, ETR, Fv/Fm; ΔF/Fm´, *Triticume aestivum*, *Zea mays*.

Introduction

Wind erosion and emissions of dust can lead to practical impacts on ecosystem processes, at scale ranging from individual plants or even smaller up through local and regional scales to global scale with biogeochemical cycle (Okin et al. 2008). Northern Africa is known as the major source of dust affecting many countries in the Middle East including Iran. Available information on dust concentration in western and southern provinces of Iran including (Kermanshah and Khuzistan), which experience aeolian dust from neighboring countries indicates that average annual frequency of critical dusty days (days with visibility less than 1000 meters) varies greatly. Data collected by Iranian Meteorological Organization (IMO) indicates that in five years from 2001 to 2005 average dusty days in Dezfool, Abadan in Khuzestan Province were 87.8, 58.2 days respectively. Similar value for Kermanshah dust days is 73 days. We, therefore, selected the concentration of dust in the dust chamber as 0.5, 1 and 1.5 g/m^3 exposure with five days intervals between every exposure for a period of 30 days.

With the detection of the C_4 pathway (Hatch et al. 1966), it has become well known that this pathway enables the plant to photosynthesize at a higher rate under conditions and with the absence of this mechanism; the photosynthesis would be drastically limited by the CO_2 concentration in the intercellular spaces (Ehleringer & Bjorkman 1976). The C_4 photosynthesis compare to C_3 photosynthesis have been shown to maximal under conditions of high light density, high temperature, and limited water supply (Black 1973, Mariana et al. 2012). But, comparison of C_3 and C_4 pathways as two different photosynthesis pathways at dust exposure has become not well known. Therefore, in this work, it has been studied photosynthesis responds of C_3 and C_4 plants to dust exposure.

Materials and Methods

Plant medium

For planting wheat (*T. aestivum*) and maize (*Z. mays*), we used 12 PVC (80×30×25 cm) containers at Ecology Laboratory, Department of Biology, Razi University, Kermanshah, Iran. A mixture of sand and compost (50:50) was used over a 15 cm layer of cobles as soil. Fifty seeds of *T. aestivum* and fifty seeds of *Z. mays* were planted in each container. Following plantation, every container was covered by a black plastic sheet for 48 h. The seedlings grow in control condition at average daily temperature of 25ºC. Light was supplied by 12 metal halide lamps (3 for three containers), which provided a broad spectrum of photosynthetically available irradiance. At the soil surface in the containers, amount of quantum flux density (QFD) was 110-120µm.m^{-2}.s^{-1}. Plants have been irrigated by tap water every other day up to the wilting point acknowledged by finger touch.

Dust generator

In this experiment a typical heavy eutric combisol formed by alluvial process which collected at the bank of Gharasou River in Kermanshah Province used as dust. This heavy textured soil was grinded and passed through sieve sized (200 opening/inches) and used as a fine texture dust. We used a dust chamber and a dust generator for simulation and calibration of dust storm over the PVC containers planted with *T. aestivum* and *Z. mays*. Using transparent plastic sheet a dust chamber was made. Dimension of the dust chamber was 1× 1× 1 meters and could conveniently cover three replicates of the containers every time dust was generated into the chamber (Fig. 1).

Biomass

In order to assess productivity of planted *T. aestivum* and *Z. mays* dry and wet mass of shoot and root, stem length and root length have been measured. At every sampling, four plants unearthed completely from each vessel and cleaned thoroughly by water for removing debris. Length of leaf, stem and root of plant have been measured by caliper and each part weighted by an electronic Balance (SCALTEC-SPB42). In order to obtain the dry mass, fresh leaf has incubated at 60ºC for 48 h and weighted to get dry mass.

Measurement of chlorophyll content

Chlorophyll content of aerial part of *T. aestivum* and *Z. mays* obtained using Arnon (1949) method. At the end of experiment, four individual leaf were collected from each container and cleaned thor-

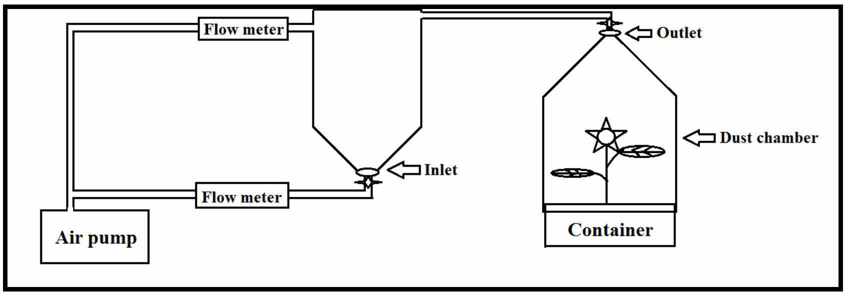

Figure 1. Schematic presentation of the dust generator and dust chamber was used in present study.

oughly by water, then 0.2 g fresh leaf from each sample was separated, grinded in a mortar with 5 ml of (80%) acetone (acetone: water 80:20 v:v) and 15 ml of (100%) acetone. After, the absorbance at A645 and A633 was read in the spectrophotometer instrument. For calculation, Arnon's equation was used to convert absorbance measurements to mg Ch/g leaf tissue:

Chl *a* (mg/g) = [(12.7 × A663) - (2.6 × A645)] × ml acetone /mg leaf tissue

Chl *b* (mg/g) = [(22.9 ×A645) - (4.68 ×A663)] × ml acetone /mg leaf tissue

Total chlorophyll= Chl *a* + Chl *b*

Fluorescence measurement

In order to gain useful information about the photosynthetic performance of *T. aestivum* and *Z. mays* from measurement of chlorophyll fluorescence yield, was used with a portable, pulse amplitude, modulated fluorometer (MINI-PAM, S/N:PYAA0421). Maximal (Fm) and basal (F_o) fluorescence yield were determined in dark-adapted (30min with leaf clip) leaves, whereas steady-state (F_s) and maximal (Fm) fluorescence yields were sampled in light-adapted leaves (Maxwell and Johnson, 2000). For determination of fluorescence yield, in dark-adapted was used (Fv=Fm-F_o) and light-adapted (ΔF=Fm´-F_s) leaves. Potential (Fv/Fm) and effective (ΔF/Fm´) quantum efficiency of photosystem II (PSII) calculated (Genty et al. 1989). Electron transport rate (ETR) through PSII was calculated as (0.5×0.84×PFD×ΔF/Fm´) assuming that 84% of incidental light is absorbed by leaves and 0.5 was used as the fraction of excitation energy distributed to PSII (Schreiber et al. 1995). All measurements of chlorophyll fluorescence were taken under laboratory conditions at saturating PPFD on the same leaves. Temperatures leaf and PPFD incident at leaf were determined by the leaf clip holder of the mini-PAM.

Statistical analysis

Statistical analysis was performed using the SPSS statistical package version 16.0. The analysis of the variance (ANOVA) appropriate for the design was carried out to detect the significance of the differences ($P≤0.05$) between the treatment and control means. Tukey-HSD test was also performed to compare the significant difference between groups. Difference from the control was considered significant as $P≤0.05$. All the values presented in this paper were expressed as the means of three replicates ± standard error (S.E).

Results

Shoot and root dry mass

The influence of exposure to different concentration of dust on leaf biomass and relative growth rate (RGR) during the course of the experiment is illustrated in Fig. 2a and b and Fig. 3. While at the onset of the experiment there was not a significant difference between treatments and control, the effect of dust on shoot biomass appeared on day 10 in *T. aestivum* and on day 20 in *Z. mays*. In *T. aestivum*, leaf dry mass

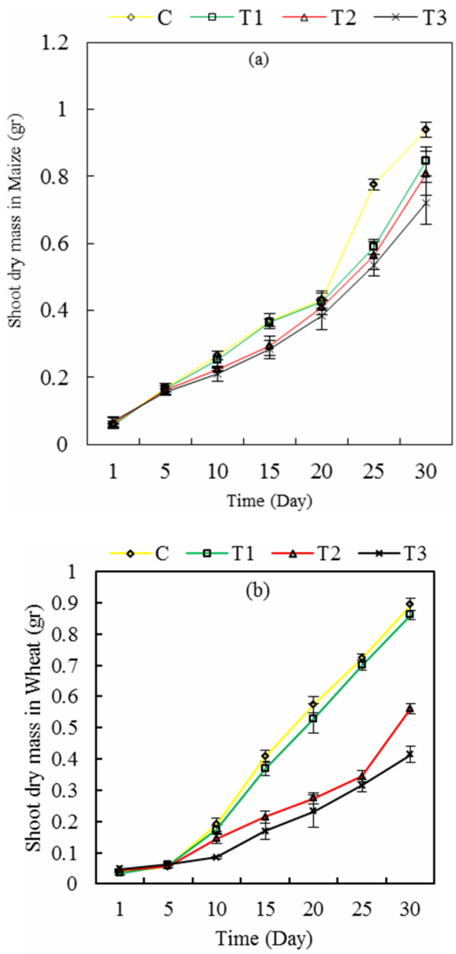

Figure 2. Effect of dust on leaf dry mass in *Z. mays* (a) and *T. aestivum* (b) exposed to 0.5, 1 and 1.5 g/m³ of dust in the dust chamber. Error bars indicate one standard error of the mean. T1, T2, T3 and C represent treatment 1, 2, 3 and control.

shows a significant difference in T3 at 0.05 confidence level using single factor analysis of variance (ANOVA, Tukey-HSD test). While, this parameter in *Z. mays* illustrated a significant difference in T3 compare to control ($p≤0.05$). The amounts of reductions in *T. aestivum* were 10%, 24% and 60% for T1, T2 and T3 respectively. Also, the reduction percentages in *Z. mays* were 1%, 5% and 11% for T1, T2 and T3 respectively. At final stage of experiment in *T. aestivum*, control compare with T1 had not significant difference but compares to T2 and T3 had significant difference ($p≤0.05$). Also, the amounts of decreasing were 4%, 37% and 54% for T1, T2 and T3 orderly. In case of *Z. mays*, at 30 days of experiment, control compare T1, T2 and T3 had not significant difference

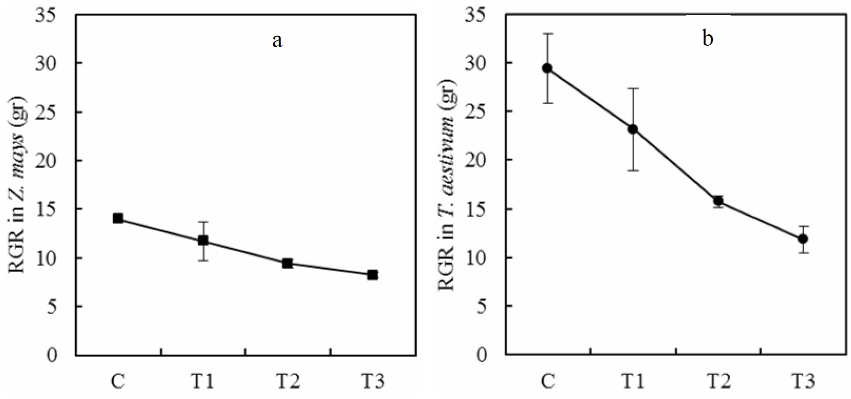

Figure 3. Effect of dust on relative growth rate (RGR) in *Z. mays* (a) and *T. aestivum* (b) exposed to 0.5, 1 and 1.5 g/m³ of dust in the dust chamber. Error bars indicate one standard error of the mean. T1, T2, T3 and C represent treatment 1, 2, 3 and control.

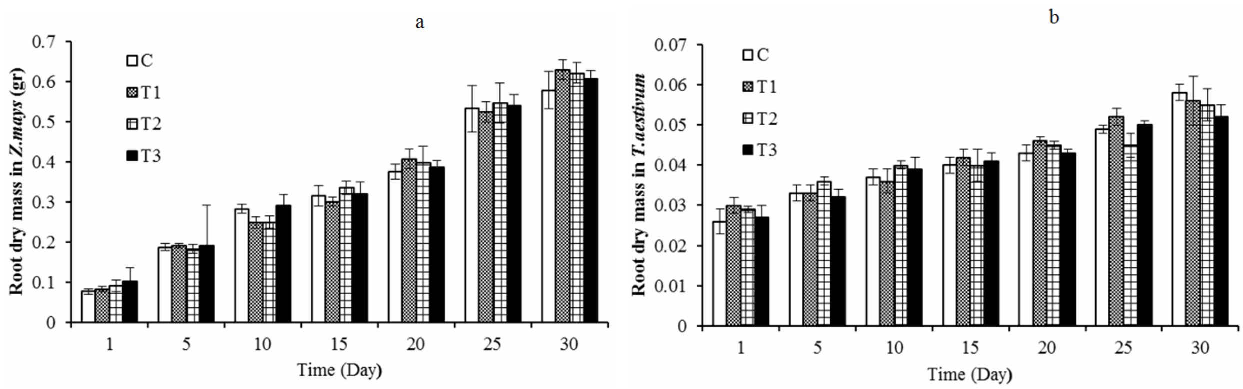

Figure 4. Effect of dust on Root dry mass in *Z. mays* (a) and *T. aestivum* (b) exposed to dust in the dust chamber. Error bars indicate one standard error of the mean. T1, T2, T3 and C represent treatment 1, 2, 3 and control.

($p \leq 0.05$). The amounts of decreasing were 2%, 14% and 24% for T1, T2 and T3 respectively. In spite of diminishing effect of dust concentrations on plant shoot (leaf and stem) plant root performed no reaction to the dust exposure. Both *T. aesitume* and *Z. mays* did not illustrate any significant difference between control with all treatments in root dry mass (Fig. 4).

Stem and root length

Exposure to dust concentrations (0.5, 1 and 1.5 g/m³) demonstrate effects on the length of shoot in *T. aestivum* and *Z. mays*, although after third stress length of shoot in T2 compare to control had significant difference at 0.05 level and T3 compare with control had significant difference at 0.05 level. The amounts of reduction were 5%, 14% and 17% for T1, T2 and T3 respectively. T1 compare to T2 had not significant difference but it compare with T3 illustrated meaningful difference at 0.05 level. Also, there was no significant difference between T2 with T3. At 20 days of experiment the amounts of reduction rose, as control compare with T1 had meaningful difference at 0.05 level and compares T2 and T3 had significant difference. After four stresses at 25 days, control compares with T1 and T2 had significant difference at 0.05 levels and compare with T3 had significant difference at 0.05. At final stage, control compare to T1 had not significant difference and compare with T2 and T3 demonstrated meaningful difference. The amounts of decreasing were 6%, 9% and 13% for T1, T2 and T3 respectively.

In related to *Z. mays*, reductions were different than to *T. aestivum*. As, at 25 days, control compare to T1 and T2 had not significant difference at 0.05 level ($p \leq 0.05$), but compare o T3 had significant difference. There was no meaningful difference within treatments. The amounts of decreasing were 7%, 12% and 15% for T1, T2 and T3 respectively. At end of experiment, statistics analysis did show that control compare to T1 had not significant difference at 0.05 level and compare T2 had significant difference and compare with T had meaningful difference. T1 compare to T2 had not significant difference but compare with T3 had significant difference ($p \leq 0.05$). The amounts of reduction were 3%, 13% and 19% for T1, T2 and T3 respectively (Fig. 5). Root length both *T. aestivum* and *Z. mays* not shows regular and significant difference as same as shoot dry mass (Fig. 6).

Chlorophyll a and b

The impact of dust concentrations at 0.5, 1 and 1.5 g/m³ on chlorophyll *a* content in *T. aestivum* is presented in Table 1. It is evident that the exposure to dust concentrations has caused a striking reduction in chlorophyll *a* content as shown in T1, T2 and T3 compared to control. Statistical analysis (Tukey-HSD test) illustrates that control had significant difference at 0.05 level compare to T2 and compare with T3 but had not significant compare to T1. Also, there was no significant difference within treatments. The percentages of reduction were 17%, 33% and 39% for T1, T2 and T3 respectively. Chlorophyll *a* in *Z. mays* reduced with exposure to dust concentration. As, control compare to all treatments had not significant difference at 0.05 level. The amounts of decreasing were 16%, 30% and 35% for T1, T2 and T3 respectively (Table 2).

In case of *T. aestivum*, the reduction in chlorophyll *b* con-

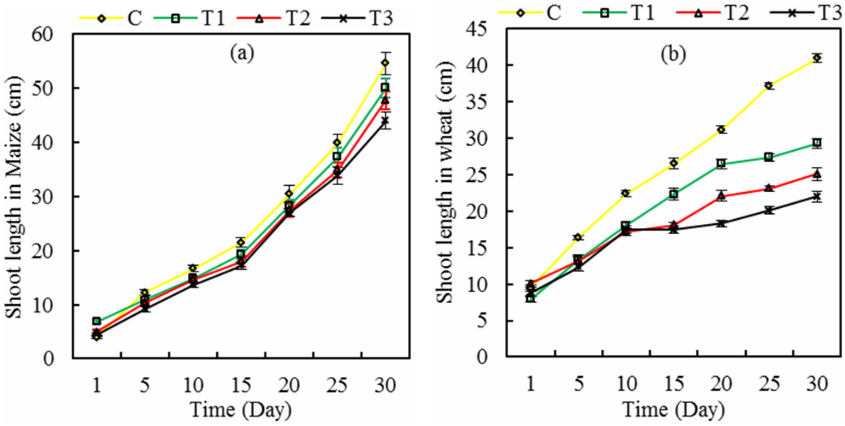

Figure 5. The effect of induced dust storm on the length of shoot in *Z. mays* (a) and *T. aestivum* (b) that exposed to 0.5, 1 and 1.5 g/m³ of dust in the dust chamber. Error bars indicate one standard error of the mean.

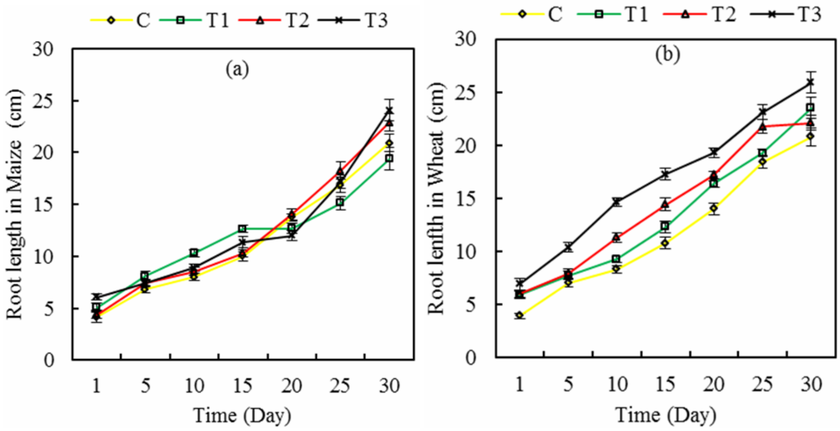

Figure 6. Impact of induced dust storm on the length of stem in *Z. mays* (a) and *T. aestivum* (b) that exposed to dust in the dust chamber. Error bars indicate one standard error of the mean..

Table 1. Mean plus standard error of chlorophyll *a*, *b*, yield, ETR, Fv/Fm and NPQ in *T. aestivum* at 0.05 significant difference (Tukey-HSD) after 30 days of experiment.

Factors	Control (±SE)	Treatment 1 (±SE)	Treatment 2 (±SE)	Treatment 3 (±SE)	*p*-value
Chl *a*	1.104±0.106	0.913±0.076	0.742±0.043	0.673±0.015	0.01
Chl *b*	0.738±0.047	0.704±0.072	0.64±0.05	0.29±0.091	0.03
Yield	0.495±0.032	0.469±0.027	0.374±0.03	0.338±0.027	0.03
ETR	93.21±2.665	74.66±3.511	62.53±2.593	49.52±2.486	0.01
Fv/Fm	0.732±0.031	0.711±0.022	0.682±0.027	0.62±0.036	0.05
NPQ	1.785±0.236	1.96±0.235	3.13±0.31	3.17±0.405	0.02

Table 2. Mean plus standard error of chlorophyll *a*, *b*, yield, ETR, Fv/Fm and NPQ in *Z. mays* at 0.05 significant differences (Tukey-HSD) after 30 days of experiment.

Factors	Control (±SE)	Treatment 1 (±SE)	Treatment 2 (±SE)	Treatment 3 (±SE)	*p*-value
Chl *a*	0.972±0.059	0.823±0.052	0.678±0.114	0.632±0.094	0.07
Chl *b*	0.539±0.178	0.409±0.081	0.347±0.079	0.22±0.027	0.27
Yield	0.523±0.028	0.483±0.035	0.441±0.03	0.386±0.026	0.01
ETR	108±4.156	95±3.77	84±2.9	74±2.66	0.01
Fv/Fm	0.781±0.021	0.763±0.024	0.727±0.024	0.693±0.032	0.09
NPQ	4.92±0.54	4.94±0.99	5.03±0.65	5.41±0.63	0.96

tent of the plant exposed to 0.5 and 1 g/m³ is not significant (Table 1). However, higher concentration of dust exposure (1.5gr) had caused significant differences in chlorophyll *b* content of the leaf. T1 compare T3 had significant difference and T2 compare with T3 had significant difference ($p \leq 0.05$). The amounts of reduction were 5%, 13% and 60%. In *Z. mays*, reduction in chlorophyll *b* in all treatments was not significant. Also, reduction percentages of parameter were 24%, 36% and 59% for T1, T2 and T3 orderly (Table 2).

Chlorophyll fluorescence

Exposure to dust on leaves of *T. aestivum* and *Z. mays* cause reduction in the amount of ΔF/Fm´, ETR and Fv/Fm compare to control sample. ΔF/Fm´ of control samples of *Z. mays* compare to T1 and T2 not illustrated meaningful difference but compare with T3 had significant reduction ($p \leq 0.05$). The reduction amounts were 8%, 16% and 26% for T1, T2 and T3 respectively. In *T. aestivum*, the amounts of reduction was higher, as control compare to t1 had not significant difference at 0.05 level but compare with T2 demonstrated significant reduction and compare to T3 illustrated significant decreasing. Reduction rates were 5%, 25% and 32% for T1, T2 and T3 respectively (Table 1).

Also, in case of ETR, control samples of *T. aestivum* than to three treatments had the significant difference at 0.05 levels. T1 compare to T2 had significant reduction and compare with T3 shows significant difference. T2 compare with T3 had significant difference. The amounts of decreasing were 20%, 33% and 47% for T1, T2 and T3 orderly (Fig. 8.10). In *Z. mays*, control compare to T1 illustrated significant decreasing and compare with T2 and T3 shows significant reduction at 0.05 level. T1 compare T2 shows no significant difference but compare with T3 had 0.05 level of significant difference. Also, T2 compare with T3 had not significant reduction. The amounts of decreasing were 12%, 22% and 32% for all treatments respectively. Fv/Fm in *T. aestivum* did show meaningful reduction in T3 and not illustrated significant difference at 0.05 level in T1 and T2. Reduction amounts were 3%, 7% and 16% for all treatments orderly. *Z. mays* illustrated lower reduction, as control compare to all treatments had not meaningful difference at 0.05 level. Also, the amounts of decreasing were 2%, 7% and 11% for T1, T2 and T3 respectively (Table 2).

Discussion

The values of the quantum yield presented in this study suggest that there are differences between *T. aestivum* and *Z. mays*. In *T. aestivum* reduction of Quantum yield as photosynthesis criteria for T2 and T3 was significant difference at 0.05 level, while *Z. mays* had significant difference at T3 only. In addition, there are significant difference between C_3 and C_4 species at biomass, chlorophyll *a, and b*. For Shoot biomass, difference between two plants was significant after 30 days of experiment. Difference between C_3 and C_4 plants in biomass amounts in this study illustrated that photosynthesis capacity in C_3 is lower compare to C_4. These differences showed that with increasing of dust deposition and time, C_4 and C_3 plants have different response to dust exposure. *T. aestivum* and *Z. mays* illustrated clear difference in chlorophyll content at T2 and T3 with 1and 1.5 g/m^3 dust concentration. Chlorophyll content is important substance in absorb the radiation and therefore with reduction of amount chlorophyll result in photosynthesis reduction. Dust size in this investigation was 2-15μm. Stomata diameter also is often 8-12μm for a range of crops (Farmer 1993). Therefore with deposition of dust on the leave, stomata blocked and result in CO_2 exchange reduction.

T. aestivum in CO_2 high concentration has higher capacity to use of CO_2. Adversely, *Z. mays* as C_4 plants by photosynthesis C_4 pathway utilize lower CO_2 compare to *T. aestivum*. Therefore, with reduction of CO_2 concentration in both outer and inner environment of leaves, C_4 plants are more successful than to C_3 plants (Wolfe et al. 1997).

Plants use two fundamental pathways, the C_3 and C_4 cycles for carbon fixation during photosynthesis (Wolfe et al. 1997). At high CO_2/O_2 ratios, because of the addition energy expense needed to concentrate CO_2 in the bundle-sheath cells, C_4 plants are disadvantaged relative to C_3 plants. However, C_4 plants can achieve a relatively high quantum yield by suppressing photorespiration at low CO_2/O_2.The evolution of C_4 plants illustrated an adaptation to the reduction CO_2/O_2 ratio in Earth history (Huang et al. 2001). Study on the photosynthesis of several C_3 and C_4 crop species has been showed that C_4 plants have markedly higher capacity in uptake of CO_2 compare to C_3 plants (Ehleringer & Bjorkman 1976). As the blocked stomata in leaves showed CO_2 exchange reduction (Farmer 1993). Naidoo and Chirkoot (2004) showed that coal dust by block the stomata might inhibit CO_2 exchange and result in reduce photosynthesis in *Avicennia marina*. This study showed that C_4 plants have higher resistance compare with C_3 plants to dust stress.

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