

*Full Length Research Paper*

# Photosynthetic responses of pea plants (*Pisum sativum* L. cv. Little marvel) exposed to climate change in Riyadh city, KSA

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**Pots study was conducted to determine interactive effects of climate change (NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub>) on photosynthetic responses in pea. The seeds of pea plants (*Pisum sativum* L. cv. Little marvel) were grown full-season in three pots arranged at four localities in Riyadh city, KSA. Photosynthetic rates (P<sub>n</sub>) were measured three times during vegetative and reproductive stages with portable gas exchange system (LI-COR 6400). In general, P<sub>n</sub> rates were highly stimulated at Elseferat area and highly reduced at the 2<sup>nd</sup> Industrial city but variable at other localities in Riyadh city. The data showed continuous increases in P<sub>n</sub> rates during pre-flowering and early seed formation and drops during late seed formation stage. This study supports that the agricultural areas could have a protective role against adverse impacts of gases exposure in highly polluted areas.**

**Key words:** Photosynthesis, growth stages, pea, gases, KSA.

## INTRODUCTION

Many models are available to assess the impacts of climate change on biochemical processes of crops and their productivity (Stockle et al., 2002; Ali et al., 2002). Greenhouse gases have abilities to absorb infrared radiation being emitted by Earth resulting in the reemission of this energy into the troposphere. Also, tropospheric gases are vary widely over the earth's surface such as in KSA and are influenced by a number of factors including localized meteorological parameters, levels of solar radiation as influenced by latitude, proximity to carbon emission centers, background levels of O<sub>3</sub> precursors including volatile organic carbons (VOC's) and other reactive organic compounds in the air mass, and long range transport processes (Krupa and Kickert, 1989; Barnes and Wellburn,

1999).

Global climate change treatments influence leaf photosynthesis rates predominately and have little or no direct effect on structural traits such as height, leaf angles, and vertical leaf distribution; nor do they exert an influence on light transmission through a leaf or through the canopy. However, treatment effects on leaf area can explain the difference in canopy photosynthesis (Teughels et al., 2005; Stockle et al., 2002). All greenhouse gases like nitrogen dioxide (NO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>) and ozone (O<sub>3</sub>) have fundamental effects on CO<sub>2</sub> exchange by plants. The CO<sub>2</sub> uptake (photosynthesis) may be affected, with the net C gain allocated to different plant processes. The P<sub>n</sub> is the most famous parameter affected by gases pollution (Saxe, 1991). Studies of photosynthesis are important to understand the effect of air pollutants including stress on crops (Miller, 1988). Chronic high levels of exposure to O<sub>3</sub> air pollution may produce responses such as reduced photosynthetic rates and earlier senescence

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of leaves, reduced stomatal conductance, reduction in growth and yield of crops and natural vegetation (Krupa and Kickert, 1989; Mulchi et al., 1992; Hakan et al., 1996). Yunus et al. (2006) showed that regional levels of  $O_3$  are likely continuing to increase as major cities (e.g. Riyadh, Cairo, Mexico and Bombay) continue to show rapid population growth and use of fossil fuels in automobiles and industries.

Unsworth and Black (1981), on soybean, noted that  $O_3$  caused seed yield losses which were related to the reduction in leaf area (LA) and leaf area duration (LAD). In addition to the reduction in LA (less photosynthetic leaf tissue) with increasing  $O_3$  concentration, leaves became less efficient in converting atmospheric  $CO_2$  into seed yield as was suggested by the reduced seed yield to LAD ratio. Also, the  $P_n$  rates of wheat plants were reduced when they exposed during senescence to several concentrations of  $O_3$  such as 15, 30, 70 and 100  $nmol O_3 mol^{-1}$  full seasons for 8 h per day (Lehnher et al., 1988)

Soybean plants exposed to chronic  $O_3$  doses also had reduced leaf  $P_n$  rates with increased  $O_3$  concentrations (Reich et al., 1986; Mulchi et al., 1992). Chernikova (1998) found only minimal responses in  $P_n$  to increased  $O_3$  exposures for soybean cultivars during pre-flowering; however, during podfill,  $P_n$  rates declined in a linear fashion over the range of  $O_3$  levels 27 to 60  $nmol O_3 mol^{-1}$ . The reduction in  $P_n$  rates of bean plants during chronic  $O_3$  exposure observed early in the growing season (0 to 44 days after emergence), but recovered over night. Later in the season, (i.e. 60 days after emergence), photosynthetic capacity and stomatal conductance gradually decreased as the severity of  $O_3$  injury increased (Sanders et al., 1992). The  $P_n$  is stimulated in  $C_3$  species under increased intercellular  $CO_2$  concentration due to increased carboxylation of Rubisco (Bowes, 1991). However, sensitivity to high  $CO_2$  concentrations might be reduced over time due to saturated  $CO_2$  binding to Rubisco and limited regeneration of ribulose 1,5-bisphosphate (RuBP) and/or inorganic phosphorus (Pi) (Stitt, 1991). Barnes and Pfirrmann (1992) exposed radish plants to two levels of  $O_3$  (24 h mean of 20 and 73  $nL L^{-1} O_3$ ) and two levels of  $CO_2$  (around 380 and 760  $\mu L L^{-1} CO_2$ ) and measured photosynthesis rates at 14, 22 and 27 days after treatment exposure. They observed that  $O_3$  decreases the  $P_n$  rates after 14 and 22 days exposure.

This study aims to investigate the possible interactive effects of  $NO_2$ ,  $SO_2$  and  $O_3$  on photosynthetic rates of pea plants grown in pots at four localities in Riyadh city, KSA.

## MATERIALS AND METHODS

### Design

This study was initially carried out at the greenhouse of Botany and Microbiology Department, College of Sciences, King Saud University, KSA. The soils of 24 pots were seeded at the beginning of December, 2007 with pea plants (*Pisum sativum* L. cv. Little marvel) and amended with fertilizers at the rates recommended for

plants and pre- or post-emergence herbicide was applied to control weeds. Irrigation units were utilized to maintain soil moisture levels near field capacity of all pots at the greenhouse. Pea plants were grown in pots two weeks until reaching maturity of vegetative growth. Then, 6-pots were transferred to four localities in Riyadh city namely: Elsefarat area, King Abdullah road area, Alsaahafah area and the 2<sup>nd</sup> Industrial city area. Two moisture regimes well-watered (3-pots) and restricted water (3-pots) conditions are included for each locality.

### Climate

Air and soil temperatures were recorded. Monthly concentrations of ambient  $NO_2$ ,  $SO_2$  and  $O_3$  were measured using AEROQUAL series-200 Monitor with multi-heads (Air Monitors Limited, UK).

### Leaf photosynthesis rates

Leaf photosynthesis rates ( $\mu mol m^{-2} s^{-1}$ ) under different exposures from four localities emissions were measured from all pots with a portable closed gas exchange system (Model LI-6400 primer, LI-COR, Lincoln, NE). Photosynthesis measurements were taken three times during vegetative, flowering and reproductive growth stages of pea plants on expanded leaves of the upper canopy under direct sun light. The  $P_n$  rates were measured on three plants per pot three times per day 10.00 am, 12 and 2.00 pm.

### Pea yield

Pea yield was calculated for harvested plants after reaching the maturity and removing pods and seeds from each plant. Pods were lengthed and weighed. Seeds were left until reaching the constant weight. The collected seeds were weighed for each pot and expressed as g/pot.

### Statistical analysis

Treatments mean were separated using least significant difference comparisons. Data analyzed using analysis of variance (ANOVA) procedures. Significant was tested at the  $P \leq 0.05$  levels. The software developed by the SPSS (ver. 11) was used to perform all analysis.

## RESULTS

### Changes in climate

The measurements of temperature for the air surrounding pea plants and soil temperature are shown in Table 1. Gradual increase occurred in air temperature for all growth stages till reaching 2 pm. The soil temperature for all growth stages was not taking clear manner.

Changes in mean concentrations of  $NO_2$ ,  $SO_2$  and  $O_3$  during the growth stages of pea at four localities, Riyadh, KSA are listed in Table 2. Mean concentrations of  $O_3$  gradually increased from vegetative to reproductive stages for all studied localities reaching maximum in reproductive stage of the 2<sup>nd</sup> Industrial city area at 2 pm being 108  $nL L^{-1}$  and recording the lowest concentration in

**Table 1.** Mean values of air and soil temperatures ( $^{\circ}\text{C}$ ) for surroundings and pots of pea at different growth stages under four air quality localities treatments in Riyadh city, KSA.

| Localities                           | Growth stages | Air temperatures |       |      | Soil temperatures |       |      |
|--------------------------------------|---------------|------------------|-------|------|-------------------|-------|------|
|                                      |               | 10 am            | 12 pm | 2 pm | 10 am             | 12 pm | 2 pm |
| Elsefarat area                       | Vegetative    | 18               | 20    | 21   | 11                | 12    | 13   |
|                                      | Flowering     | 20               | 21    | 22   | 13                | 14    | 14   |
|                                      | Reproductive  | 23               | 24    | 26   | 14                | 15    | 16   |
| King Abdullah road area              | Vegetative    | 19               | 20    | 21   | 12                | 12    | 13   |
|                                      | Flowering     | 20               | 21    | 22   | 13                | 14    | 14   |
|                                      | Reproductive  | 23               | 24    | 26   | 15                | 16    | 18   |
| Alsahafah area                       | Vegetative    | 18               | 19    | 20   | 11                | 12    | 13   |
|                                      | Flowering     | 20               | 21    | 22   | 13                | 14    | 14   |
|                                      | Reproductive  | 23               | 24    | 26   | 14                | 15    | 16   |
| 2 <sup>nd</sup> Industrial city area | Vegetative    | 22               | 23    | 24   | 12                | 14    | 17   |
|                                      | Flowering     | 25               | 26    | 27   | 14                | 14    | 18   |
|                                      | Reproductive  | 26               | 28    | 29   | 15                | 15    | 18   |
| LSD ( $P < 0.05$ )                   |               | 3.2              | 3.1   | 3.4  | 2.9               | 3.5   | 4.3  |

**Table 2.** Mean values of  $\text{NO}_2$ ,  $\text{SO}_2$  and  $\text{O}_3$  concentrations ( $\text{nL L}^{-1}$ ) for pea grown in pots at different growth stages under four air quality localities treatments in Riyadh city, KSA.

| Localities                           | Growth stages | $\text{NO}_2$ concentrations |       |      | $\text{SO}_2$ concentrations |       |      | $\text{O}_3$ concentrations |       |      |
|--------------------------------------|---------------|------------------------------|-------|------|------------------------------|-------|------|-----------------------------|-------|------|
|                                      |               | 10 am                        | 12 pm | 2 pm | 10 am                        | 12 pm | 2 pm | 10 pm                       | 12 pm | 2 pm |
| Elsefarat area                       | Vegetative    | 12                           | 13    | 14   | 11                           | 12    | 13   | 22                          | 23    | 23   |
|                                      | Flowering     | 13                           | 14    | 14   | 13                           | 14    | 14   | 24                          | 24    | 25   |
|                                      | Reproductive  | 15                           | 16    | 16   | 14                           | 15    | 16   | 26                          | 27    | 26   |
| King Abdullah road area              | Vegetative    | 18                           | 23    | 25   | 22                           | 24    | 23   | 44                          | 65    | 73   |
|                                      | Flowering     | 20                           | 25    | 23   | 23                           | 24    | 25   | 54                          | 64    | 77   |
|                                      | Reproductive  | 23                           | 24    | 24   | 25                           | 26    | 23   | 55                          | 66    | 78   |
| Alsahafah area                       | Vegetative    | 17                           | 19    | 17   | 18                           | 19    | 17   | 43                          | 44    | 45   |
|                                      | Flowering     | 19                           | 22    | 22   | 25                           | 32    | 34   | 52                          | 54    | 54   |
|                                      | Reproductive  | 21                           | 24    | 22   | 22                           | 22    | 23   | 56                          | 60    | 54   |
| 2 <sup>nd</sup> Industrial city area | Vegetative    | 24                           | 25    | 24   | 23                           | 24    | 27   | 77                          | 84    | 88   |
|                                      | Flowering     | 28                           | 29    | 33   | 28                           | 31    | 32   | 82                          | 88    | 98   |
|                                      | Reproductive  | 32                           | 34    | 33   | 32                           | 34    | 37   | 88                          | 94    | 108  |
| LSD ( $P < 0.05$ )                   |               | 5.5                          | 3.4   | 4.2  | 4.3                          | 5.3   | 4.8  | 9.8                         | 11.4  | 12.1 |

vegetative stage of Elsefarat area being  $22 \text{ nL L}^{-1}$ . Also, gradual increase in  $\text{SO}_2$  and  $\text{NO}_2$  concentrations was observed. For both gases, high values were recorded in the 2<sup>nd</sup> Industrial city area during hot months being  $34 \text{ nL L}^{-1}$  at 12 pm and  $37 \text{ nL L}^{-1}$  at 2 pm for  $\text{NO}_2$  and  $\text{SO}_2$ , respectively.

### Responses of leaf photosynthesis

Effects of  $\text{NO}_2$ ,  $\text{SO}_2$  and  $\text{O}_3$  on leaf  $P_n$  measured at three growth stages under two soil moisture regimes are summarized in Table 3. Generally, the  $P_n$  values were higher under wet conditions comparing to that at dry treat-

**Table 3.** Mean values of leaf photosynthesis rates ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) for pea at different growth stages under four air quality localities treatments and two soil regimes in Riyadh city, KSA.

| Localities                           | Growth stages | P <sub>n</sub> rates |       |      | P <sub>n</sub> rates |       |      |
|--------------------------------------|---------------|----------------------|-------|------|----------------------|-------|------|
|                                      |               | Well-watered         |       |      | Restricted-watered   |       |      |
|                                      |               | 10 am                | 12 pm | 2 pm | 10 am                | 12 pm | 2 pm |
| Elsefarat area                       | Vegetative    | 250                  | 270   | 290  | 230                  | 250   | 220  |
|                                      | Flowering     | 420                  | 440   | 400  | 360                  | 390   | 380  |
|                                      | Reproductive  | 330                  | 350   | 330  | 250                  | 260   | 230  |
| King Abdullah road area              | Vegetative    | 220                  | 230   | 200  | 190                  | 200   | 200  |
|                                      | Flowering     | 290                  | 300   | 260  | 230                  | 250   | 220  |
|                                      | Reproductive  | 220                  | 250   | 210  | 200                  | 210   | 200  |
| Alсахafah area                       | Vegetative    | 240                  | 270   | 250  | 210                  | 240   | 220  |
|                                      | Flowering     | 300                  | 330   | 300  | 290                  | 300   | 280  |
|                                      | Reproductive  | 230                  | 250   | 200  | 200                  | 230   | 190  |
| 2 <sup>nd</sup> Industrial city area | Vegetative    | 200                  | 230   | 200  | 180                  | 200   | 190  |
|                                      | Flowering     | 250                  | 260   | 270  | 200                  | 230   | 220  |
|                                      | Reproductive  | 190                  | 220   | 210  | 170                  | 200   | 180  |
| LSD ( <i>P</i> < 0.05)               |               | 35                   | 41    | 55   | 42                   | 34    | 23   |

**Table 4.** Mean values of pods and seeds characters for pea at different growth stages under four air quality localities treatments and two soil regimes in Riyadh city, KSA.

| Localities                           | Water treatments | Pods characters   |             |         | Seeds characters |      |            |
|--------------------------------------|------------------|-------------------|-------------|---------|------------------|------|------------|
|                                      |                  | Fresh wt (gm/pot) | Length (cm) | No./pot | No./ pot         | %    | Yield (gm) |
| Elsefarat area                       | Well-            | 52.4              | 7.98        | 12      | 75               | 18.3 | 854.5      |
|                                      | Restricted-      | 45.5              | 7.11        | 10      | 71               | 17.2 | 8.41.2     |
| King Abdullah road area              | Well-            | 35.4              | 5.23        | 8       | 49               | 12.7 | 701.0      |
|                                      | Restricted-      | 33.3              | 5.01        | 6       | 44               | 11.0 | 700.2      |
| Alсахafah area                       | Well-            | 42.3              | 6.91        | 9       | 55               | 15.7 | 778.3      |
|                                      | Restricted-      | 38.2              | 6.11        | 7       | 51               | 14.3 | 741.3      |
| 2 <sup>nd</sup> Industrial city area | Well-            | 31.5              | 4.47        | 6       | 25               | 10.1 | 676.1      |
|                                      | Restricted-      | 30.5              | 4.12        | 5       | 22               | 9.2  | 655.5      |
| LSD ( <i>P</i> < 0.05)               |                  | 9.21              | 1.43        | 2       | 15               | 5.61 | 42.5       |

ments. The P<sub>n</sub> rate values were increased gradually starting from 10 am of vegetative growth stage reaching up at 12 pm of flowering stage but decreased slightly at the stage of reproductive. Pea plants grown in pots at studied localities exhibited big difference in P<sub>n</sub> values. The data showed that Elsefarat area had the highest values of P<sub>n</sub> being 440  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 12 pm, while the 2<sup>nd</sup> Industrial city area recorded the lowest values of P<sub>n</sub> being 190  $\mu\text{mol m}^{-2} \text{s}^{-1}$  at 10 am of well-watered conditions. In general, leaves of pea plants grown under enriched NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub> at King Abdullah road and 2<sup>nd</sup> Industrial city areas had lower P<sub>n</sub> rates than other ones grown under less gas pollutants. In few cases, the gases enrichment had no significant effect on P<sub>n</sub> rates under dry conditions, while significant differences between all studied localities and the time of measurements. Chronic NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub>

exposure tended to more reduce P<sub>n</sub> rates at 10 am but these results were significant when compared to that ones measured at 2 pm. Significant lower P<sub>n</sub> rates were observed at 10 am and 2 pm for all growth stages and highly variations between localities of restricted water conditions.

### Responses of yield quality

The NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub> induced a significant (*P* < 0.01) decline in pea plant grain yields in both soil moisture regimes (Table 4). The ambient-air treatments of highly polluted localities (2<sup>nd</sup> Industrial city area) also reduced the number of fresh weight of pod, length of pod, number of pos per pot and pods per pot. The treatments of 2<sup>nd</sup>

Industrial city area and King Abdullah road area reduced the pod length by 44 and 34%, respectively. The number of seeds per pod of pea plants exposed to Elseferat area air pollution was significantly higher than that of plants treated with air pollution of other localities. In case of number, pea seeds per pot recorded the highest values of well-watered treatments at Elseferat area being 75, while the lowest values recorded at 2<sup>nd</sup> Industrial city area being 22. Maximum and minimum losses in pea seed % are similar to number of pea seeds per pot.

## DISCUSSION

Climate changes (NO<sub>2</sub>, SO<sub>2</sub>, O<sub>3</sub>), predominantly a warming of the ecosystems, caused soil carbon to decrease overall, especially in desert. They alone project a carbon loss after 50 years (Hall et al., 1995). Also, global climate change treatments influence leaf photosynthesis rates predominantly by decreased production of CO<sub>2</sub> (Teughels et al., 2005). The pea plant (C<sub>3</sub>) species exhibited significant responses to the atmospheric treatments. The mechanism(s) involved a possible protective role via CO<sub>2</sub> production. In addition, the results from the present study support a hypothesis that these CO<sub>2</sub> concentrations somehow protects the pea's ability to partition the photosynthates to developing sinks as grains.

The collected data from this work supported that the elevated CO<sub>2</sub> can increase the productivity of pea plant in less polluted areas (Elseferat, Alshahafah). DaCosta et al. (1986) suggested that CO<sub>2</sub> release or uptake of a full crop in the field could be predicted with reasonable accuracy from knowledge of the air temperature and soil moisture content. On the other hand, cultivated pea plants at highly polluted areas (King Abdullah, 2<sup>nd</sup> Industrial city) may produce less CO<sub>2</sub> which lead to less photosynthesis. Electron microscope examination of climate change (NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub>) injury revealed that the considerable disruption including tonoplast rupture may have caused a complete disruption of the osmotic balance within the cell inactivating the photosynthetic process (Sanders et al., 1992). Also, the sensitivity of P<sub>n</sub> to air pollutants is affected by genotypes (Reich and Amundson, 1985; Miller, 1987), development stage (Lehnher et al., 1988), and various environmental factors such as light intensity, ambient CO<sub>2</sub> levels, nutrient status and water availability (Runeckles, 1992). Leaves of pea grown in pots at all study localities recorded less P<sub>n</sub> rates in compared to Elseferat locality. This reduction in P<sub>n</sub> rates of pea plants during senescence are might be associated with increased stomatal conductance and decrease in various components of the photosynthetic apparatus such as chlorophyll concentration, soluble protein, adenylates, RuBP regeneration, and Rubisco (ribulose 1,5-biphosphate carboxylase/oxygenase) activity. Farage et al. (1991) concluded that the first inhibitory effect of NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub> on P<sub>n</sub> is a loss of carboxylation efficiency (i.e. CO<sub>2</sub> uptake/internal leaf CO<sub>2</sub> concentration) due to de-

creased activity of Rubisco. Also, this may be attributed to the fact that plants were fully acclimated to the CO<sub>2</sub> enriched environment (Allen, 1990).

During the later stages of vegetative growth, perhaps CO<sub>2</sub> was no longer a limiting growth factor. During this period, sink capacity becomes limited and P<sub>n</sub> rates are likely become reduced due to a possible accumulation of starch grains in the chloroplast which triggers feedback mechanisms that inhibit photosynthesis (Stitt, 1991). However, during the late handling process and during the early handling process, significant CO<sub>2</sub> effects were again observed which might be attributed to the greater demand for carbohydrates in response to increased sink capacity by the plant (Woodward et al., 1991; Stitt, 1991). Later in the season, when plants were in the ripening stage, no significant difference was found but plants grown under enriched CO<sub>2</sub> presented higher P<sub>n</sub> rates for each of the two last readings (early seed formation and late seed formation), respectively. This can be attributed to a small delay in leaf senescence observed for plants grown under enriched CO<sub>2</sub>. Barnes et al. (1995) reported that interactions between carbon assimilation, carbohydrate status and chemical composition (nutrient status) may dictate the manner in which plants respond to rising CO<sub>2</sub> concentrations, and governed the ability of the plant to sustain its positive response to CO<sub>2</sub> enrichment.

Pea plants recorded less photosynthetic rates and low yield under low irrigated water for all studied localities. Restricted water in soil affect vegetation during reproductive stages for cotton where yields were lower in response to increase in the rate of boll abscission (Grimes et al., 2007). Early stress caused square shedding and a subsequent depression in bloom rate; mid-season stress decreased boll retention and hastened cutout (i.e. temporary cessation of growth and blooming); and late stress caused abscission of almost all young bolls but not of older bolls (Grimes et al., 2007). On the other hand, well-watered conditions gave the best yield. This is due to its influence soil properties, and hence physiological and internal biochemical activities of plants. Water stress induces a decrease in leaf water potential, which causes reductions in the rates of photosynthesis assimilation (Havaux and Lannoye, 1985). Photosynthesis in alfalfa plant was inhibited by about 35% (Nicolodi et al., 1988) and in soybean by 71% (Dornbos et al., 1989) during severe moisture deficits. The effect of short-term water stress on photosynthesis in sunflower hybrids differing in productivity under field conditions was examined by Gimenez et al. (1992). They found that the amount of chlorophyll and soluble protein did not differ significantly between hybrids. Water stress developed over four days decreased the assimilation rates of both hybrids by a similar degree. Changes in the amounts of chlorophyll and soluble protein were small and were not sufficient to explain the decrease in photosynthesis; neither was observed decreases in stomatal conductance.

Agriculture soils at Elseferat area may also increase the root growth of pea plants. This may lead to increase plant

efficiency for retrieval of nutrients from soil. Timlin et al. (1992) suggested that a major factor in nutrient transport mechanisms in soil is root distribution of plants. The response to elevated CO<sub>2</sub> involve increasing the rates of photosynthesis and growth, especially increased allocation of carbon below ground, particularly root exudates, sloughing of root tissues, death of fine roots and mycorrhizae readily available carbon in soil (Zak et al., 1993). Varvel (1994) indicated that C could be sequestered at 10 to 20 g m<sup>-2</sup> yr<sup>-1</sup> in some cropping systems with sufficient levels of N fertilizer. Greater storage of C in soil suggests CO<sub>2</sub> emissions from agriculture soils could be increased in the long term and may have significant effect on CO<sub>2</sub> in the atmosphere under current climatic conditions.

The effects of NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub> were found to be the cause of large changes in grains quality. Reduction of grain yield in pea in response to gases levels induced stress was attributed to reduced P<sub>n</sub> due to early senescence and reduced capacity of plants to provide photosynthetic assimilate to grains (Lehnherr et al., 1987; Miller, 1987). Also, the decrease in photosynthetic rates paralleled the content of Rubisco (Lehnherr et al., 1987) in response to premature senescence of the flag leaf triggered by O<sub>3</sub>-induced stress (Lehnherr et al., 1987). Kull et al. (1996) explained the impact of O<sub>3</sub> on plants by depression of photosynthetic activity and the accelerated senescence of leaves. Moreover, a genotype considered tolerant with normal CO<sub>2</sub> levels appears to have decreased O<sub>3</sub> tolerance with elevated CO<sub>2</sub>.

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