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Soil Microbial Biomass of Pea (*Pisium sativum* cv. Little Marvel) in Response to Three Atmospheric Air Regimes at Al Baha Region, KSA

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Abstract

This study was conducted to determine the effect of atmospheric air on soil health in pots involving the growth of pea under two soil moisture regimes. Twelve pots were treated with three air quality treatments of urban, suburban and rural sites. *In situ* soil respiration increased under urban and suburban while it decreased little under rural site atmospheric conditions. These data support the relationships between the number of microorganisms in soils and carbon dioxide fluxes. Microbial biomass, metabolic quotient and crop yields or biomass were found most sensitive indicators of soil quality, which significantly varied in response to air quality and soil moisture regimes. The soil microbial biomass, metabolic quotient, and basal respiration were the most practical quality index variables; however, when using only a single predicator, microbial biomass was the most sensitive indicator of the soil quality.

Keywords

Microbial Biomass, Atmospheric Sites, Pea Cultivars, Moisture Regimes

1. Introduction

Studies regarding to the effect of air quality on soil microbial biomass are little. Soils play an important role in controlling background concentrations of most air pollutants. Soil quality is an important focus because it expresses both the inherent properties of a soil and its functional capacity [1]. The relationships between elevated CO_2 and C-below flow in soil are very important. Mooney and Koch [2] suggested that the biomass accumulation enhanced CO_2 with increase allocation of C below ground more than above ground at 4:1.

The impacts of changes in atmospheric composition on vegetation cover will thus have importance effects on soil food webs, organic matter dynamics, soil biological processes, mineral weathering and nutrient ion relations and water relations [3] [4] [5]. The dependency of respiration rate on air temperature differs for conditions of wet and dry soil with a threshold of soil water potential around—1 - 2 MPa. About 70% - 94% of variation in full-crop respiration rate can be attributed to variation in air temperature and soil water content [6].

Rogers *et al.* [7] noticed an increase in total bacterial counts in the rhizosphere of cotton exposed to enriched CO_2. There was a greater standing crop of mycorrhizal root tips at the highest CO_2 treatment compared with two lower CO_2 treatments. Tingey *et al.* [8] found that mycorrhizae and fungal hyphae occurrence increased in response to CO_2 treatment. Ozone significantly reduced assimilation/respiration ratios in shoots of both mycorrhizal and non-mycorrhizal plants. McCrady and Andersen [9] investigated impact of O_3 on the carbon balance of the mycorrhizae, providing the necessary tools for later evaluating the extent of O_3's impact on seedling carbon budget.

Removal of O_3 by a soil is dependent not only on the rate at which the molecules of O_3 are removing by the complex soil surface itself, but also by the magnitude of the layer of relatively still air adjacent to the soil surface. This layer of air still acts as a barrier for the exchange of any gases between the soil and the atmosphere, and must be considered in both field and laboratory measurements [10]. Wullschleger *et al.* [11] concluded that plant and litter/soil microbial responses to elevated CO_2 and possibly increased O_3 will have long term impacts on the cycling of C and N in litter/soil.

Hogsett and Andersen [12] indicated that O_3, exposure which results in less allocation of C below ground, should decrease soil CO_2-efflux (respiration). However in a simple ecosystem with two competing plant species (Ponderosa pine seedlings and blue stem rye grass) growing in a native ponderosa pine soil with intact soil food-web, exposed to O_3, resulted in actually an increase in soil CO_2 efflux and soil organic matter after the period of exposure [9].

The objective of this research was to examine the effect of three air quality (urban, suburban and rural sites) on soil microbes, soil respiration and soil quality of pea plants.

2. Materials and Methods

2.1. Study Design, Treatments and Ozone Analysis

This study was conducted in KSA during 2013-2014 growing seasons. It concerned with the long-term impact of ambient air quality treatments and two soil moisture regimes. The Little marvel cultivar of pea (*Pisum sativum* L.) were grown in pots for 12 months, which span one growing seasons. The pots were equipped with 80-cm diameter × 50-cm high, which was purged at a rate of 28-$m^3 \cdot min^{-1}$ with treated gases. There were 3 complete replicates with three pots treatments per replicate *i.e.* three sites treatments and two moisture regimes. The three air quality treatments were: rural, suburban and urban sites during the

growing seasons. Also, the soil moistures are well-watered vs. restricted conditions. Ozone concentrations in study sites were measured started in July, 2013 till June 2014 over pea life cycle using AEROQUAL series-S200 Monitor version 4 with removable multi-sensors heads (Air Monitors Limited, UK).

2.2. Soil Collection and Analysis

The used soil type was loamy sand. The soil has about 40% sand, 21% clay and 31% silt and others. The bulk density, water holding capacity, total porosity and pH are 1.34 $g \cdot cm^{-3}$, 2.23 $mm \cdot cm^{-1}$, 49.5% and 5.9%, respectively. Soil samples (depth 0 - 10 cm) were collected from each site (urban, suburban and rural) during early pod-fill period and examined for changes in their chemical characters and microbial populations, while soil respiration rates using soil LI-COR measured monthly in the field (description of measuring method in respiration rate section). Soil temperature measured using thermometer during the life of peas while air temperatures were collected from Al Baha (KSA) metropolitan station.

2.3. Microbial Populations of Soil

Soil-root rhizosphere samples were used to enumerate the bacterial and fungi numbers. The numbers of organisms were estimated by the plate dilution frequency assay [13] [14] using plate count agar for bacteria, and a modified rose Bengal agar [15] for fungi. These numbers were converted to number of organisms per gram of soil using appropriate dilution factors.

2.4. Soil Respiration Rate & Specific Maintenance Respiration (qCO_2) Rate

Soil respiration rate was measured using *in vitro* static soil incubation and *in situ* dynamic soil chambers studies [1]. *In vitro* soil respiration rates were measured using about 20 g ODE (oven-dried equivalent) of soil at 60% WFP (water-filled porosity) placed in 50-mL glass beaker. Each soil sample was placed in 1-L glass Jar along with vial containing 10 ml of distilled water to maintain humidity and a plastic vial containing 10 ml of 1M NaOH to trap evolved CO_2. The soil respiration rate (mg/kg/d) was calculated as:

$$\left(CO_2 \text{ soil} - CO_2 \text{ air}\right)/10 \text{ days}$$

As described by Islam [1], *in situ* soil respiration rates were measured using a model 6000-09 soil respiration chamber attached to a Model 6200 Portable Photosynthesis System (LICOR, Inc., Lincolyn, NE). Specific maintenance respiration rate (mg/g/d) was determined by dividing the mean daily CO_2-C evolution (*in vitro* soil respiration rate) by the microbial biomass [16].

2.5. Soils Microbial Biomass Carbon (C_{TMB}) and Metabolic Quotient (qR)

Total microbial biomass carbon was measured by the microwaved soil extraction

method [17]. About 20-g ODE) of 2-mm sieved field-moist homogenized soil was placed in each of two 50-mL glass beakers. The soils were adjusted to ≈80% WFP by allowing air-drying or by slowly adding water, as needed. The soil in one beaker was microwaved at 800-j·g^{-1} ODE soil using a 650-W microwave oven. Exactly 5 g ODE of microwaved and field-moist soils were taken in 50 mL polycarbonate tubes and extracted with 20 mL of M K_2SO_4 (pH 7.0) by horizontal shaking at 250 rpm for 60 minutes. The soil suspensions were centrifuged at 5000 rpm for 5 minutes followed by filtration with VWR 494 filter paper to obtain soil-free extracts to measure organic C. A rapid microwave digestion procedure for spectrophotometric measurement of extracted organic C was used [18]. Exactly 5.0 mL of filtered extract was digested in a 125 mL Erlenmeyer flask with 5-mL of 0.17 M $K_2Cr_2O_7$ and 5 mL of concentrated H_2SO_4 by microwave energy applied at 500-j·mL^{-1} of digestion mixture. A short stem 25-mm glass funnel was kept at the digestate at 590 nm was measured by spectrophotometer. Sucrose C solutions were also digested and used to standardize the absorption readings. The C_{TMB} measured as extracted C (mg/kg) was calculated as follows:

$$C_{TMB} = C_{EXTMW} / K_{ME}$$

where C_{EXTMW} equals the net flush of C from the difference between the extracted C in MW and field-moist soils, and K_{ME} (0.213) represents the fraction of the C_{TMB} extracted by 0.5 M K_2SO_4. Metabolic quotient (g/100g C_T) was determined after dividing the amount of microbial biomass C by total amount of C_T [19].

2.6. Statistical Analysis

All data were analyzed using analysis of variance (ANOVA) procedures appropriate for a random factorial design. Mean differences among the time of testing samples were evaluated by the Least Significant Difference (LSD) method at $P < 0.05$ level of significance. All statistical analyses were performed using the software developed by the SPSS (ver. 11).

3. Results

3.1. Ozone Measurements

Monthly means of annual O_3 concentrations at three sites of air quality regimes are contained in **Table 1**. The average over all months O_3 concentration for urban conditions equaled 97 nl·l^{-1} which was somewhat higher than values determined to suburban air equaled 86 nl·l^{-1}. Several prolonged periods of cloudy weather particularly during first and the second weeks of January-March with very low build up in the atmosphere likely caused lower than normal results. The ambient O_3 levels were increased gradually over study period hot months, while cold month's recorded O_3 levels were stable. The rural sites lowered the ambient O_3ranged between 14 to 21 nl·l^{-1}.

3.2. Microbial Biomass of Soil

Microbial counts in the pea rhizosphere soils from the pots under atmospheric

Table 1. Variations of O_3 concentrations during study period at three sites in KSA.

O_3 Concentrations/months	Control	Urban	Suburban	Rural
July, 2013	15	123	111	21
August	15	124	113	21
September	15	100	96	17
October	15	88	87	16
November	15	87	86	17
December	15	85	86	15
January, 2014	15	66	65	14
February	15	65	62	15
March	15	96	87	17
April	14	99	88	18
May	14	98	89	18
June	15	117	108	17

air enrichments and two moisture regimes over three sample periods are shown in Table 2. Bacterial and fungal populations were not significantly affected by the moisture treatments. Urban air enrichment tended to inhibit the growth of microorganisms in the soil rhizosphere while atmospheric rural treatments typically increased the microbial populations in the soil. The suburban treatment increased populations.

The combination of air quality treatments with moisture regimes generally showed increase in microbial populations under urban air for both moisture conditions; however, suburban treatment results are consistently lower than the rural air controls but are normally not significantly different. Although the data from both moisture regimes were somewhat varied over the crops and years, the patterns of results appeared generally. Similarly, under the two moisture regimes are obtained. The interaction of air quality treatments vs. moisture treatments was non-significant in most cases for bacterial counts but significant for fungal numbers in soils (Table 2). Under the wet treatments, fungal counts for the urban treatments were significantly higher than rural controls in results combined over dates and crops; however, results for suburban were all comparable to rural controls. Also, the suburban treatments had fungal counts larger than rural controls on two dates under the dry treatments. Both suburban and urban treatments stimulated the fungal counts compared to rural controls in the combined results while the results for the suburban treatments were generally non-significant (Table 2). Bacterial counts were also stimulated by the urban treatments but suburban and rural treatment effects were largely non-significant.

Table 2. Mean values for microbial populations in pea rhizosphere soil.

Treatments	Bacterial #/g ode ($\times 10^8$)	Fungi #/g ode ($\times 10^3$)
	Moisture	
Wet	1.47a♣	1.45a
Dry	1.36a	1.78a
	Air quality	
Control	1.05a	0.82
Rural	3.53b	2.42b
Urban	0.40a	1.50a
Suburban	1.37a	1.62a
	Air quality × Wet moisture	
Control	1.15a	0.78a
Rural	4.06b	2.52b
Urban	0.42a	0.75a
Suburban	0.86a	1.59a
	Air quality × Dry moisture	
Control	0.94a	0.88a
Rural	2.99b	2.40b
Urban	0.38a	2.26b
Suburban	1.16a	1.65a

CF = Carbon-filtered, NF = Non-filtered air, and ode = Oven-dry equivalent rhizosphere soil. ♣Values followed by the same letter are not significantly different.

3.3. Soil Respiration

3.3.1. *In Situ* Soil Respiration

Field measured respiration fluxes were significantly higher under the tropospheric rural enrichment treatments than for the suburban treatment (Figure 1). Also, soils under elevated tropospheric urban concentration at had lower respiration flux rates than other treatments. Elevated tropospheric urban decreased the respiration flux in both wet and restricted moisture conditions compared to other treatments. The suburban of elevated enrichments had respiration rates, typically higher than the charcoal filtered air controls but slightly below the rates for elevated urban. The pots maintained under well-watered conditions normally exhibited higher respiration rates than under dry conditions. The temperature of both air and soil decreased gradually from beginning of July 2013 until end of measurements in June, 2014. Soil respiration rates increased from the beginning of July until mid of September then declined until the November 2014 results. In general, air quality treatments had significantly increases in soil respiration for the rural treatments but decreased under the urban treatments when compared to carbon-filtered treatment (control).

Data for soil respiration rates for the pots when planted by pea are listed in Figure 1 and Figure 2. For the 2014 measurements, soil respiration fluxes for all

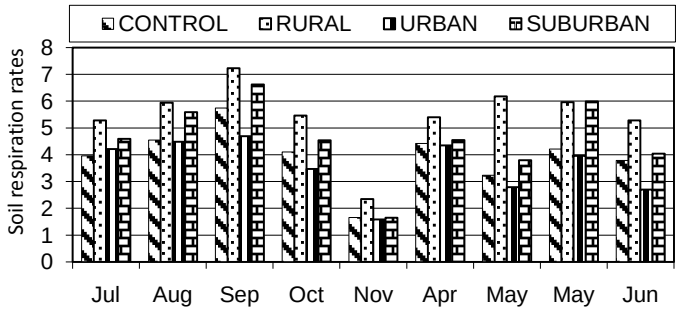

Figure 1. *In situ* soil respiration rates (u mol CO_2 m^{-2}/s^{-1}) for soils supporting pea grown in pots under three air quality treatments and wet soil.

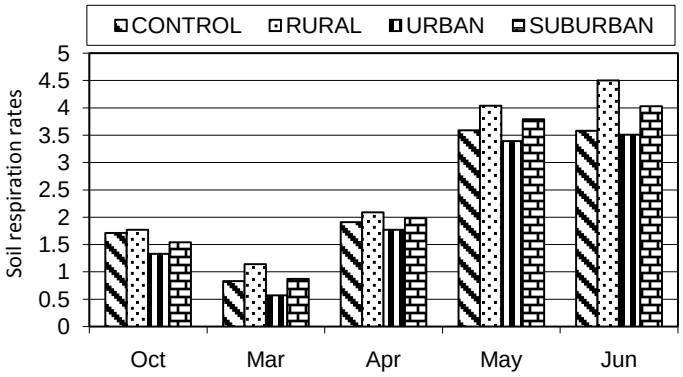

Figure 2. *In situ* soil respiration rates (u mol CO_2 m^{-2}/s^{-1}) for soils supporting pea grown in pots under three air quality treatments and dry soil.

dates had no significant differences among pea plants while the wet conditions exhibited strong positive effects on soil respiration rates for all measurement dates.

The flux rates for rural from soils were increased gradually from the beginning of March until the last measurements for the pea in June. Air temperatures during the spring of 2014 were not taking constant manner, while soil temperatures increased from March to June. The soil respiration rates responded significantly to the elevated rural treatments for all measurement dates; however, the reduction in respiration rates in response to elevated rural alone were significant only at the initial reading in March 2014. The suburban treatments were significant only for the June 2014 results. In most instances, the patterns of CO_2 flux responses observed in the wet pots were also noted in the restricted moisture pots except the values in the dry treatments which were consistently lower than were observed in the higher moisture pots having the same air quality treatments.

Soil of pea in 2014 showed non-significant differences in CO_2 flux rates for moisture treatments **Figure 1** and **Figure 2**. Air temperature means were generally higher each monthly reading with soil temperatures showing progressively higher values each month from April through June 2014. The effects of air quality treatments on CO_2 flux rates from the pea in 2014 were significantly different on all dates. Significant increases were observed in response to the rural treatments for all dates and significant decreases in CO_2 flux in response to the urban

treatments were observed for all dates. The effects of elevated rural in combination were typically higher than the controls being significantly different. In general, the interaction of soil moisture treatments and air quality treatments were non-significant with results from both moisture regimes exhibiting similar patterns of responses regarding soil respiration rates.

3.3.2. *In Vitro* Soil Respiration

Laboratory conducted basal respiration rates for soils collected from pea in pots under air quality and soil moisture stresses are illustrated in Figure 3 and Figure 4. The enhanced atmospheric urban and rural concentration results indicate significant increase and decrease in basal respiration activities, respectively, compared to carbon filtered air control. Also, the suburban elevated the *in vitro* CO_2 release rate when compared to the urban treatments. Similar result pattern obtained under the three air quality treatments for the two soils moisture regimes with the rates for the low moisture pots being lower than well-watered pots.

3.4. Selected Soil Properties

Results for selected soil quality properties from the pea plants at three sites are shown in Table 3. They are repeated for reader convenience when introducing

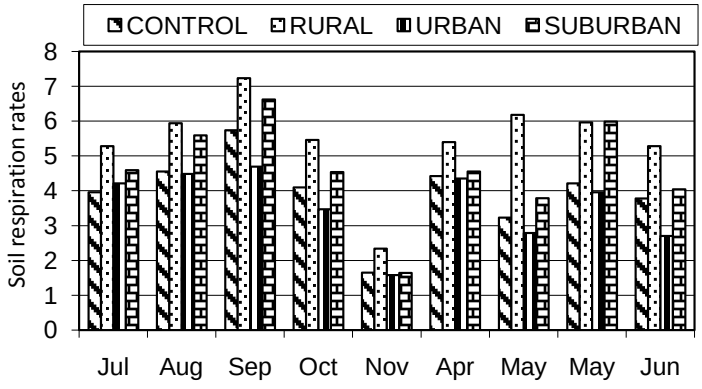

Figure 3. *In vitro* soil respiration rates (u mol CO_2 m^{-2}/s^{-1}) for soils supporting pea grown in pots under three air quality treatments and wet soil.

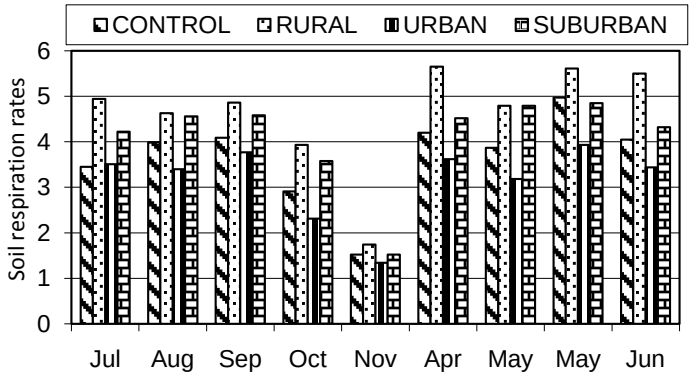

Figure 4. *In vitro* soil respiration rates (u mol CO_2 m^{-2}/s^{-1}) for soils supporting pea grown in pots under three air quality treatments and dry soil.

Table 3. Mean values of selected soil properties in pea rhizosphere soil.

Soil treatments	C_{TMB} M CO_2 m^{-3}	C_{AMB} M CO_2 m^{-3}	qR (%) C_{TMB} C_{ORG}^{-1}	qR (%) C_{AMB} C_{ORG}^{-1}	qR (%) C_{TMB} C_{AMB}^{-1}	Yield (g)
			Moisture means			
Wet	1.99a♣	0.98a	1.66a	0.98a	28.33a	188a
Dry	1.88a	0.91a	1.66a	0.96a	27.66a	88b
			Air quality means			
Control	2.44a	0.95a	1.75a	0.98a	27.88a	108a
Rural	2.46a	0.95a	1.77a	0.99a	27.99a	105a
Urban	2.11b	0.77b	1.65b	0.67b	27.23b	90b
Suburban	2.17b	0.73b	1.43c	0.23c	27.78a	103a
			Air quality × wet moisture means			
Control	4.44a	1.65a	3.00a	1.23a	30.23a	112a
Rural	4.45a	1.45a	2.99a	1.33a	31.02b	112a
Urban	2.52b	1.24b	2.48b	1.02b	29.23c	93b
Suburban	2.73b	1.25b	2.48b	1.10b	29.56c	99b
			Air quality × dry moisture means			
Control	4.44a	1.65a	3.00a	1.23a	30.23a	112a
Rural	4.32a	1.33b	2.88a	1.21a	30.77a	101a
Urban	2.11b	1.11c	2.23b	1.09b	29.00b	88b
Suburban	2.35b	1.15c	2.48b	1.12b	29.26b	95b

C_{TMB} = Total microbial biomass C, C_{AMB} = Active microbial biomass C, qR = Metabolic quotients, C_{ORG} = Total soil organic C, qCO_2 = Mean daily BR C_{TMB}^{-1}. ♣Values followed by the same letter are not significantly different.

soil quality indexes computations. Combined over air quality treatments, the soil moisture variables produced significant differences for five of the nine soil quality characteristics. In all cases, the restricted moisture treatments were lower than values from the high moisture pots. Those properties that were affected by moisture include metabolic quotient, basal respiration, and total microbial biomass C (Table 3). Combined over soil moisture treatments six of the nine soil characteristics exhibited increased values for rural treatments and seven of the nine soil quality index parameters were decreased by the urban treatments when compared to the charcoal filtered control treatments. However, in most cases, the maximum differences were found when comparing the urban vs. the rural treatments which represent the enhanced urban vs. the enhanced rural air quality effects. In general, the patterns of responses for the air quality treatments were similar under both moisture regimes with the magnitude of the differences among treatments being much larger under the well-watered pots. The properties that were increased in response to the rural treatments under well-watered conditions include CTMB, CAMB, qR, and BR. Those soil properties that were diminished under the rural treatments under well-watered conditions include

CTMB, qR, BR, CPO, C_{min} and CEC (Table 3). Those soil quality parameters that were largely unaffected for air quality treatments of CT.

Specific maintenance respiration (qCO_2) rates, *i.e.* CO_2 release per unit of microbial biomass in soil, were increased under the high O_3 treatments with the rural being significantly higher than urban treatment when combined under soil moisture levels (Table 3). However, the interactive effect of the suburban treatments and soil moisture treatments were highly significant. Under high moisture, the rural treatment stimulated the qCO_2 rate over the urban treatments. Under the low moisture conditions, the qCO_2 rates for the suburban treatment were stimulated over the rural air control.

4. Discussion

The main role of microbial activity in flux of CO_2 from soil can be a significant component of the carbon budget in any ecosystem. Norman *et al.* [20] found that in a prairie environment, soil surface CO_2 fluxes were comparable to daily gross photosynthetic rates when averaged over 24 hours. Monteith *et al.* [21] found that up to 20% of net CO_2 uptake by a crop could originate in soil. There were strong positive responses to increased soil respiration under atmospheric CO_2 concentrations. Elevated tropospheric O_3 decreased the CO_2 fluxes in both moisture regimes for both crops. These results agree with that obtained by Edwards [22]. Varied significant interactions of CO_2 with O_3 and moisture were observed. The results for microbial populations exhibited similar patterns to that for soil respiration where significant increases were found in both bacteria and fungi in rhizosphere soil subjected to high CO_2 effects and large decreases under high O_3 treatments. The respiration of roots, decay of organic matter, and activity of microbes primarily produce soil CO_2 [22] [23] [24] [25]. Soil respiration is very dependent on soil temperature, organic content, moisture content and precipitation [26] [27] [28]. *In situ* soil respiration rates data were significantly higher under rural and well-watered treatments. Similar results were found by Vose *et al.* [29]; Prior *et al.* [30]; Schortemeyer *et al.* [31], Van Ginkel *et al.* [32] and Randlett *et al.* [33].

Significant relationships were found between the effects of CO_2 and O_3 treatments, and C fractions, CO_2 fluxes and microbial numbers. The observed differences in size of active to intermediate organic C fractions are indirectly supportive of the hypothesis that elevated tropospheric CO_2 or O_3 concentrations produced quantitative and qualitative changes in C which accounted for most of the differences in dynamics of soil respiration. Islam *et al.* [18] reported that soil organic C under CO_2 enrichment is of a more decomposable quality (*i.e.* easily oxidizable nature) for efficient metabolism by C_{TMB} than in soils under ambient or O_3 stress conditions. Measurement of CTMB has been used as an indicator of early changes in CT that modify dynamics of soil respiration long before any changes can be detected by CT [34].

Greater proportions of microbial biomass (qR) and smaller qCO_2 (C respired per unit of microbial biomass) have been suggested as indications of shift in C

quilibrium toward C sequestration processes in soil [19] and [35]. Presence of active and high microbial biomass populations allowed for efficient C use which resulted in a higher qR [19] [36]. A higher qR under tropospheric CO_2 enrichment was maintained, because CCO_2 was efficient in assimilation of organic C which resulted in a decrease in the overall rate of CO_2 respired per unit of microbial biomass. These data suggest that soils under tropospheric CO_2 enrichment had more active microflora to carry out an efficient microbial metabolism in response to increased photosynthetic translocation of labile C below-ground and thus act as net sink for tropospheric CO_2 compared to ambient air. Smaller qR values under higher tropospheric O_3 exposures, compared to carbon- filtered air control, can be explained in several ways. As ecosystems under stress have smaller qR and respiration flux, and greater CO_2 than more stable ecosystems [35], smaller qR and CO_2 fluxes under suburban treatments could suggest that the C_{TMB} was under greater stress from lack of sufficient C sufficient. A relatively high qCO_2 in soil under suburban treatments is an indication of environmental stress that agrees with Odum [37] who reported that to repair damages under stress requires soil microbes to divert an increasing amount of energy from growth and reproduction for maintenance and survival. This concept is supported in the current study by low values for microbial populations, microbial biomass, *in situ* soil respiration and higher values for qCO_2 in soils under high O_3 concentration compared to the soils from the CF controls. High maintenance respiration suggests lower metabolic efficiency *i.e.* microorganisms mineralized the C but assimilated a smaller percentage into their cells [36]. Thus, the larger qCO_2 is inversely proportional to the metabolic qR clearly a decrease suggests and/or fewer active populations of C_{TMB} under high troposphetic O_3 treatments. More energy from organic carbon is needed by the soil microflora to maintain cell integrity and survival under high tropospheric O_3 environments. In this study, the data suggest that a substantial fraction of the C_{TMB} being suppressed by soybean-wheat plants exposed to tropospheric O_3 was likewise being stressed. As a result, more C was mineralized as CO_2 and transferred to the atmosphere; therefore, such soils acted as net sources of CO-CO_2. However, the negative effects resulting from tropospheric O_3 treatments on organic C fractions and respiration appear to have been balanced by the positive effects of higher inputs of decomposable C below-ground from plants grown in soils under rural and well-watered treatments.

Significant relationships between organic C fractions (C_{TMB}, BR and qCO_2) which may be attributed to the stimulation of microbial activity in response to translocation of photosynthates below-ground. Although C_{TMB} is usually only 1% to 3% of C_T [19], increasing in microbial activity would have considerable effect on soil respiration. Islam [1] reported that an increase in C_{TMB} positively correlated with soil respiration but inversely related to qCO_2 due to efficient assimilation of organic C by higher proportions of active microbial biomass.

Among soil properties, the C_{TMB}, qR, C_{min}, CEC, BR and C_{PO} from the nine soil characteristics examined increased values under the rural treatments and decreased

under urban treatments for well-watered conditions. An improvement of soil properties under atmospheric CO_2 enrichment and wet soil conditions suggests that these soils were biologically more actives through "CO_2-induced fertilization" on plants and warmth-induced stimulation on N cycle in soil [38]. Higher biological activity may be attributed to an efficient assimilation and accumulation of organic C through C_{TMB} in soils [39]. Significant increase in C_{TMB} suggests that a small portion of total organic C may have responded more atmospheric CO_2 enrichment than the total organic C content of soil. The qR gives an indication of the metabolic activity of soils, which accounted for the assimilation and accumulation of organic C through C_{TMB} in soil. Accumulation of labile organic C is largely responsible for biological activity, fertility and enhanced soil macroaggregation which may have improved the quality of soil [40] [41]. On the other hand, the phytotoxic nature of O_3 affects the plants cellular membranes and enzyme systems, such as ATP ase [42] which may decrease the translocation of C below-ground [43]. Decreased allocation of labile C below-ground most likely affected the CTMB and its biochemical activities in soil. As most of the properties functionally associated with soil quality are largely regulated by organic matter and microbial biomass [44], a lack of sufficient amount of labile C and reduced microbial activity significantly affected soil quality properties.

5. Conclusion

Air pollution, in effect, is one of the prices we pay for our life. As such, it is something that all world population should elect decision to manage now and in the future. Progressive changes in the concentrations of atmospheric gases are likely to have significant impacts on the components of ecosystems. Increases in atmospheric O_3 air pollution have produced detrimental effects on vegetation. Soil respiration rates were significantly higher under rural and wet soil conditions. The urban treatment decreased the fluxes of CO_2 from pea soils under both soil moisture regimes. The suburban treatment counteracted the detrimental effects of phytotoxic concentrations of O_3 by increasing the soil respiration rates in soils under pea plants. This study supported significant relationships between the effects of the three air quality treatments, and C fractions, soil respiration rates and microbal populations.

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