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Elevated O_3 and wheat cultivars influence the relative contribution of plant and microbe-derived carbohydrates to soil organic matter

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ABSTRACT

Soil carbohydrates are sensitive to changes in soil C inputs because of their fast turnover rates. However, the effects of elevated O_3 on the content and composition of soil carbohydrates are rarely reported in agroecosystem. The objectives of this study were to investigate the effects of elevated O_3 on the content and composition of soil neutral sugars in the two wheat cultivars with different O_3-tolerance. Our results showed that elevated O_3 decreased the total soil neutral sugars. At the wheat ripening stage, elevated O_3 increased the contents of galactose (Gal), arabinose (Ara) and mannose (Man) in the O_3-tolerant wheat and decreased the contents of xylose (Xyl), Gal and Ara in the O_3-sensitive wheat. Significant interactive effects between elevated O_3 and wheat cultivar were found in the ratios of (Man + Gal)/(Ara + Xyl) and Man/(Ara + Xyl). These two ratios increased with elevated O_3 at the wheat ripening stage in both wheat cultivars, with higher ratios observed in the O_3-sensitive wheat relative to the O_3-tolerant wheat. Our results indicated that elevated O_3 decreased the total neutral sugars and altered the relative contribution of plant- and microbe-derived carbohydrates to soil organic matter. Microbe-derived carbohydrates were dominant contribution to the total carbohydrates in the O_3-sensitive wheat. These changes in the accumulation and origins of soil carbohydrates will influence the accumulation and decomposition of soil organic matter and ecosystem functioning in agroecosystem.

1. Introduction

Tropospheric ozone concentration (O_3) has been rising at the rate of 0.5–2% per year due to human activity (Feng et al., 2010; Singh et al., 2013) and is predicted to increase further (Vingarzan, 2004). As the most damaging and widespread phytotoxic air pollution, tropospheric O_3 poses a great threat to crop yields (Feng et al., 2008) and ecosystem carbon storage (Sitch et al., 2007), and affects the sustainable development of agroecosystem (Chen et al., 2009; Schrader et al., 2009). Although some studies have evaluated the effects of elevated O_3 on the aboveground subsystem, relatively little attention has been paid to the direct and indirect effects on soil-crop systems, especially for the accumulation and decomposition of labile soil organic matter (SOM) (Jones et al., 2009; Chen et al., 2009, 2010).

The influences of elevated O_3 on belowground are indirectly mediated by alterations in plant processes and C allocation (Andersen, 2003). Elevated O_3 has been reported to decrease the carbon allocation to roots and reduced carbohydrates levels and storage pools in O_3-exposed plants (Andersen et al., 1997). Changes in the quantity or quality of carbon flux into the soil will influence the interactions among soil organisms (Li et al., 2012; Li et al., 2013) and then alter carbon retention and mineralization in soil ecosystem (Andersen, 2003). As the labile fraction of SOM, soil carbohydrates account for about 5–25% of total SOM (Stevenson, 1994; Zhang et al., 2007). Soil carbohydrates are highly responsive to changes in C inputs to the soil because of their fast turnover rates (Schmitt and Glaser, 2011). However, the effects of elevated O_3 on the content and composition of soil carbohydrates are rarely reported in agroecosystem.

As a kind of non-cellulosic carbohydrates, soil neutral sugars initially originate from plant materials (including large proportions of pentose sugars-arabinose and xylose), however, soil micro-organisms can re-synthesize a large amounts of hexoses (galactose and mannose) and deoxysugars (rhamnose and fucose) and release

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them into the soil (Cheshire, 1979; Bock et al., 2007). Therefore, both the contents and compositions of soil neutral sugars can be used to evaluate the plant-microbe relationship on SOM dynamics (Amelung et al., 1999; Medeiros et al., 2006). Despite the significant indication of soil carbohydrates on accumulation and decomposition of SOM, the knowledge about the effects of elevated O_3 on the accumulation and origins of soil carbohydrates in SOM is still lacking (Andersen, 2003).

Wheat (*Tritcium aestivum* L.) is the second largest food crop with an annual production of about 650 million metric tons which is sensitive to the elevated O_3 (Zhu et al., 2011). In the Yangtze River Delta region, elevated O_3 reduced the yield of wheat by 10% in 1999 as predicted by Feng et al. (2003). Recently, some O_3-tolerant wheat cultivars have been reported in China, which may avoid yield reduction in a high O_3 environment (Cao et al., 2009 Zhu et al., 2011). Different physiological characters and yield components responses to elevated O_3 have been reported in O_3-sensitive and O_3-tolerant wheat cultivars (Cao et al., 2009,Zhu et al., 2011). These distinct responses of different wheat cultivars to elevated O_3 would lead to differences in the quality and quantity of plant litter and/or roots which may in turn influence the C inputs to SOM. The objectives of this research were to investigate the effects of elevated O_3 on the contents and compositions of soil neutral sugars in the two wheat cultivars with different O_3-tolerance. We hypothesized that (1) the effects of elevated O_3 will negatively affect the contents of soil carbohydrates and would subsequently be reflected in the relative contribution of plant and microbial derived carbohydrates to SOM; (2) the level of the above-mentioned changes in soil neutral sugars will exhibit cultivar dependence.

2. Materials and methods

2.1. Experimental site and O_3-FACE treatments

The experiment was conducted in a suburb of Jiangdu city in Jiangsu province of China (32°35′ N, 119°42′ E). The soil is a Shajiang Aquic Cambosols (Chinese Soil Taxonomy, Zhu et al., 2011) with a sandy-loamy texture, 15.0 g kg^{-1} total C, 1.59 g kg^{-1} total N, pH 6.8,

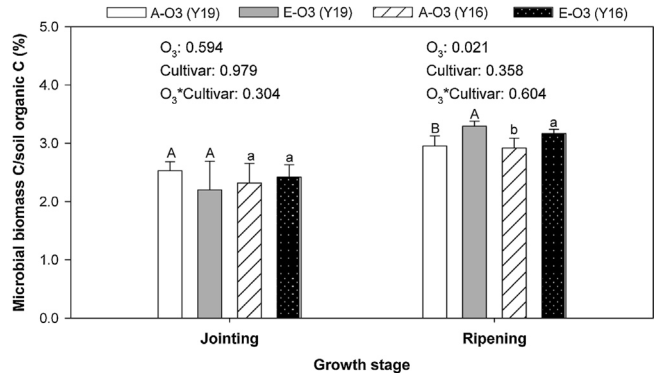

Fig. 1. The ratio of microbial biomass C to soil organic C in soil planted with O_3-sensitive (Y19) and O_3-tolerant (Y16) wheat under ambient (A-O_3) and elevated O_3 (E-O_3) conditions. Within each stage, capital and lowercase letters represent the significant differences between ambient and elevated O_3 for O_3-sensitive and O_3-tolerant wheat cultivars, respectively, bars with the same letters suggested non-significant difference in *t*-test ($P < 0.10$).

9.2% sand (1–0.05 mm), 65.7% silt (0.05–0.001 mm), 25.1% clay (<0.001 mm), and bulk density 1.2 g cm^{-3} at 0–15 cm depth (Zhu et al., 2011). The climate conditions are temperate with annual temperature and precipitation averages at 16 °C and 1100–1200 mm, respectively, and a frost-free period of >230 days (Zhu et al., 2011).

The experimental design was a split plot with the main plots being ambient O_3 or elevated O_3, and sub plots being wheat cultivars (Tang et al., 2011 Zhu et al., 2011). Three replicate elevated O_3 rings, each with 14.5 m in diameter, were set randomly within a uniform area of 4 ha to continuously provide an elevated O_3 of 60 ppb over the ambient conditions (about 40 ppb), while three replicate rings, each with the same size, were set randomly within the same area for the ambient O_3 treatment. All of the rings were far enough apart to prevent O_3 from spilling over from one ring to another. Each plot under ambient and elevated O_3 conditions was split into two subplots planting with two winter wheat cultivars (*Triticum aestivum* L.) [O_3-sensitive cultivar, Yannong 19 (Y19), and the O_3-tolerant cultivar, Yangmai 16 (Y16)]. The experimental

Table 1
Soil and plant physicochemical variables in the soil planted with O_3-sensitive (Y19) and O_3-tolerant (Y16) wheat under ambient (A-O_3) and elevated O_3 (E-O_3) conditions during wheat growth season (mean ± SD).

	Growth	A-O_3		E-O_3		Effect[f]		
	Stage	Y19	Y16	Y19	Y16	O_3	Cultivar (C)	$O_3 \times C$
MBC[a]	Jointing	401.5 ± 25.9	379.5 ± 44.9	319.4 ± 58.8	338.5 ± 57.4	ns	ns	ns
(mg kg^{-1})	Ripening	446.0 ± 24.2	497.3 ± 12.6	503.5 ± 41.4	484.5 ± 43.8	ns	ns	ns
DOC[b]	Jointing	421.4 ± 56.7	431.3 ± 20.0	459.4 ± 50.7	461.1 ± 65.9	ns	ns	ns
(mg kg^{-1})	Ripening	499.5 ± 96.2	390.0 ± 6.3	355.6 ± 16.2	313.7 ± 2.1	0.024	0.033	ns
SOC[c]	Jointing	15.90 ± 1.11	16.43 ± 0.96	14.67 ± 1.42	13.93 ± 1.12	0.065	ns	ns
(g kg^{-1})	Ripening	15.17 ± 1.70	17.10 ± 1.30	15.30 ± 1.32	15.30 ± 1.25	ns	ns	ns
TN[d]	Jointing	1.70 ± 0.09	2.07 ± 0.47	1.61 ± 0.13	1.48 ± 0.20	ns	ns	ns
(g kg^{-1})	Ripening	1.59 ± 0.19	1.78 ± 0.07	1.60 ± 0.26	1.65 ± 0.18	ns	ns	ns
Soil C/N	Jointing	9.34 ± 0.43	8.18 ± 1.51	9.11 ± 0.25	9.44 ± 0.49	ns	ns	ns
	Ripening	9.56 ± 0.08	9.61 ± 0.35	9.65 ± 0.83	9.32 ± 0.25	ns	ns	ns
TNSC/SOC[e]	Jointing	8.75 ± 0.15	8.74 ± 0.49	9.11 ± 0.67	9.64 ± 0.52	ns	ns	ns
(%)	Ripening	10.10 ± 1.31	8.69 ± 1.00	9.03 ± 0.48	9.56 ± 1.08	ns	ns	ns
Plant C (%)	Ripening	40.63 ± 0.46	40.40 ± 0.10	41.00 ± 0.10	40.73 ± 0.06	ns	ns	ns
Plant N (%)	Ripening	2.09 ± 0.24	2.16 ± 0.13	2.43 ± 0.09	2.18 ± 0.16	ns	ns	ns
Plant C/N	Ripening	19.59 ± 2.04	18.77 ± 1.09	16.86 ± 0.65	18.72 ± 1.37	ns	ns	ns
Grain yield(kg ha^{-1})	Ripening	6077 ± 451	6160 ± 122	4908 ± 293	5190 ± 370	0.001	ns	ns

[a] MBC microbial biomass carbon.
[b] DOC dissolved organic carbon.
[c] SOC soil organic carbon.
[d] TN total nitrogen in soil.
[e] TNSC/SOC percentage of total neutral sugars carbon to soil organic carbon.
[f] The effects were significant at $P < 0.10$; ns represents not significant.