NUMERICAL DATA

Ozone effects on plants in natural ecosystems (2019)

Growth and productivity

growth and productivity	O3	O3 +N	O3 —H2O
foliar biomass	n.d.	↑	↓
height growth	n.d.	↑	↓
bole diameter growth	↓	↑	↓
fine root biomass leaf surfaces	↓	↓	↑
stomatal occlusion trophic interactions	↑	n.d.	n.d.
bark beetle	n.s.	↑	↑
fungal infection ecosystem level	↑	n.d.	n.d.
Competitive indices	n.d.	↓	↑
Mycorrhizal biomass	↑	n.s.	n.s.
gas exchange	O_3	O_3 +N	O_3 —H_2O
Amax lower canopy	n.d.	↑	↓
Amax whole canopy	↓	n.d.	↓
Amax seedlings	↓↑	n.d.	n.d.
stomatal limitation	a to ps	n.d.	↑
stomatal conductance	↓	↓↑	↓
foliar respiration	n.s.	↑	↓
soil respiration	↓	n.d.	n.d.
O3 flux	↓	n.s.	↓
foliar biochemistry and tissue chemistry	O_3	O_3 +N	O_3+ —H_2O
total ascorbate	↓	↓	↑
dehydroascorbate	↑	n.d.	↓
total glutathione	↓	↑	↓
oxidised glutathione	↑	↑	↓
a Carotenoids	↑	n.d.	↓
foliar nitrogen	↓	↑	↓
C:N ratio of foliage	↑	n.d.	↓
starch	n.d.	↓	↑
chlorophyll content	↓	↑↓	↓

Effects of ozone (O_3), O_3 and nitrogen (+N) deposition, and O_3 and drought stress (—H_2O) on western yellow pine in the Sierra Nevada and the San Ber- nardino Mountains, California, USA.

Source:
https://www.researchgate.net/publication/330943630_Ozone_effects_on_plants_in_natural_ecosystems

The effects of elevated CO_2 and elevated O_3 exposure on plant growth, yield and quality of grains of two wheat cultivars grown in north India (2019)

Leaf area index (LAI) and photosynthetic rates (Pn) of HD-2967 and C-306 wheat cultivars grown under elevated CO_2 (EC), tropospheric O_3 (EO) and interactive condition of elevated CO_2 X O_3 (ECO)

Wheat variety	Treatment	Leaf Area Index (LAI)						Photosynthetic Rate (Pn; μmolem^{-2}s^{-1})					
		Vegetative stage			Flowering stage			Vegetative stage			Flowering stage		
		2016–17	2017–18	Mean	2016–17	2017–18	Mean	2016–17	2017–18	Mean	2016–17	2017–18	Mean
HD- 2967	Amb	4.5	4.6	4.5	3.9	3.9	3.9	19.9	20.6	20.3	21	19.5	**20.2**
	EC	5.7	5.6	5.6	5	4.8	4.9	23	24.8	23.9	23.8	22.3	**23**
	EO	4.1	4.2	4.2	3.5	3.7	3.6	18.9	19	18.9	19.9	18.7	**19.3**
	ECO	4.4	4.3	4.3	4.1	3.9	4	20.4	21.4	20.9	21.9	22	**22**
C-306	Amb	4.9	4.8	4.8	4.2	4.4	4.3	22.3	22	22.2	22.5	21	**21.7**
	EC	5.9	5.7	5.8	5.2	5.1	5.2	25.1	25.8	25.5	25.2	23.4	**24.3**
	EO	4.5	4.2	4.3	3.8	4	3.9	20.1	19.4	19.8	21.6	20.4	**21**
	ECO	**4.6**	**4.7**	**4.7**	**4.4**	**4.2**	**4.3**	**21.6**	**22.8**	**22.2**	**22.2**	**22.7**	**22.4**

Determination was on 40 plants (10 plants from each replicate for each treatment and growth stage during each year).

Source: https://www.sciencedirect.com/science/article/pii/S2405844019359778

The effects of elevated CO_2 and elevated O_3 exposure on plant growth, yield and quality of grains of two wheat cultivars grown in north India (2019)

Effects of elevated CO_2 (EC), tropospheric O_3 (EO) and interactive condition of elevated CO_2X O_3 (ECO) on nitrogen, crude protein, starch and C: N ratio in the grains of two wheat cultivars .

	Treatments	**2016–17**	**2017–18**	**Mean**	**2016–17**	**2017–18**	**Mean**	**2016–17**	**2017–18**	**Mean**	**2016–17**	**2017–18**	**Mean**
HD-2967	Amb	2.00	1.97	1.99	11.9	11.7	11.8	76	74	75	22.3	27.3	**24.8**
	EC	1.77	1.81	1.79	10.5	10.7	10.7	86.7	84.3	85.5	30.8	26.4	**28.6**
	EO	2.20	2.3	2.25	13.0	13.8	13.4	67	65.3	66.2	16.7	20.1	**18.4**
	ECO	1.98	2.00	1.99	11.8	11.9	11.9	77	76	76.5	29.2	22.8	**26**
C-306	Amb	2.00	1.95	1.98	11.9	11.6	11.7	72	75	73.5	23.1	28.3	**25.7**
	EC	1.80	1.83	1.82	10.7	10.8	10.8	82	84	83	27.6	31.8	**29.7**
	EO	2.33	2.22	2.26	13.9	13.2	13.5	68	66	67	21.6	18.4	**20**
	ECO	**2.09**	**2.00**	**2.05**	**12.4**	**11.9**	**12.2**	**74**	**76.3**	**75.2**	**27.4**	**24.4**	**25.9**

Determination was done on 32 samples (8 samples from each replicate for each treatment during each year).

Source: https://www.sciencedirect.com/science/article/pii/S2405844019359778

Exploring ozone pollution in Chengdu, southwestern China: A case study from radical chemistry to O3-VOC-NOx sensitivity (2018)

Table 1: The measured parameters at PZ, PX, SL and CZ averaged for the ozone pollution episode (EP1). The averaged for four measurement sites are shown and used in EKMA model calculation.

Parameters	PZ	PX	SL	CZ	Average
Temperature/°C	26.1	26.5	26.5	26.3	26.4
Pressure/hPa	945.9	948.5	955.5	955.4	951.3
RH/%	63.7	63.2	65.5	62.3	63.7
O_3/ppbv	65.4	76.4	59.7	51.4	63.2
NO_2/ppbv	12.9	13.7	19.0	26.2	18.0
CO/ppmv	0.65	0.67	0.33	0.47	0.5
Isoprene/ppbv	0.4	0.3	0.5	0.2	0.4
AHC/ppbv	24.6	22.7	25.7	33.6	26.6

Source : 10.1016/j.scitotenv.2018.04.286

Review of plants to mitigate particulate matter, ozone as well as nitrogen dioxide air pollutants and applicable recommendations for green roofs in Montreal, Quebec (2018)

Table 1: The Comparative potential of air pollutants removed by green roofs.

References	Type of Study	City	Green Roof Area (m^2)	Green Roof Cover	Type of Pollutant(s) Removed	Amount of Pollutant(s) Removed (kg)	Annual Removal per Unit Area (g/m^2)
Currie & Bass, 2008	Model	Midtown Toronto	2 432 000	Grass	Total	3050	1.25
					$^{PM}10$	880	0.36
					O_3	1270	0.52
					NO_2	650	0.27
					SO_2	250	0.10
Currie & Bass, 2008	Model	Midtown Toronto	2 432 000	Shrubs	Total	7870	3.23
					$^{PM}10$	4480	1.84
					$^{O}3$	1740	0.72
					NO_2	1240	0.51
					SO_2	410	0.17
Speak et al., 2012	Model	Manchester	500 000	Red Fescue	PM_{10}	1605	3.21
Speak et al., 2012	Model	Manchester	500 000	Creeping Bentgrass	PM_{10}	905	1.81
Speak et al., 2012	Model	Manchester	500 000	Ribwort Plantain	PM_{10}	245	0.49
Speak et al., 2012	Model	Manchester	500 000	Sedum	PM_{10}	210	0.42
Yang et al., 2008	Actual	Chicago	198 000	63% grass/low plants, 14% herbaceous plants, 11% trees/shrubs & 12% hard surfaces	Total	1675	8.45
					$^{PM}10$	234.5	1.18
					$^{O}3$	871	4.40
					NO_2	452.25	2.28
					SO_2	117.25	0.59

Note: Values for Midtown Toronto's green roof area, total pollutants removed, shrubs' amount of pollutants removed and annual removal per unit area have been calculated from Currie and Bass (2008).Values for Chicago's amount of pollutants removed and annual removal per unit area have been calculated from Yang et al. (2008).
Source: https://www.sciencedirect.com/science/article/pii/S0269749118303099

Review of plants to mitigate particulate matter, ozone as well as nitrogen dioxide air pollutants and applicable recommendations for green roofs in Montreal, Quebec. (2018)

Recommended trees and shrubs to reduce air pollutants on intensive green roofs in Montreal, Quebec.

Target air pollutant	**Recommended tree or** shrub	**Effects on the target air pollutants**	**Maximum** height (m)	**Hardiness** zone
PM	Pinus strobus 'Nana'	Pines most effectively capture PM, when compared to other plant species and contribute to	2.0	3
	Pinus mugho var. pumilio	mitigating PM all year-round.	1.5	2
	Pinus mugho 'Slowmound'		0.90	2
	Pinus pumila 'Dwarf Blue'		0.60e1.0	4
O_3	Acer palmatum 'Shaina'	Such drought-tolerant deciduous broadleaved trees with low BVOC emissions are good options 1.75		5b
	Acer palmatum 'Mikawa-	to mitigate O_3.	1.5	5
	Yatsubusa'			
NO_2	Magnolia 'Genie'	Magnolias can help mitigate NO_2 because they are both NO_2 tolerant and it is important in their 3.0e3.5		5
		metabolic pathways.		

Note: Values for Pinus strobus 'Nana', Pinus mugho var. pumilio and Pinus mugho 'Slowmound' are from Jardin 2m (2017a; 2017b; 2017c), for Pinus pumila 'Dwarf Blue' and Magnolia 'Genie' are from Pepiniere jasmin (2017a;2017b) as well as for Acer palmatum 'Shaina' and Acer palmatum 'Mikawa-Yatsubusa' are from François Lemay Nursery (2004a; 2004b). Pines effective PM capture has been demonstrated (Beckett et al., 2000a; Beckett et al., 2000b; Freer-Smith et al., 2004; Manes et al., 2016). Jim & Chen (2008) classify Magnolias as NO2 tolerant. Morikawa et al. (1998) found Magnolias to greatly metabolize NO2.

Source: https://www.sciencedirect.com/science/article/pii/S0269749118303099

Water stress mitigates the negative effects of ozone on photosynthesis and biomass in poplar plants. (2018)

Table : 1 Effects on both younger leaves (YL) and older leaves (OL) in September: Analysis of variance (P values) of the effects of O3, Water stress and Leaf Age, and their interactions on gas exchange, chlorophyll a fluorescence parameters and pigment content. Statistically significant effects (P< 0.05) are marked in bold.

	$^{O}3$	Water	Age	O_3 Water	O_3 Age	Water Age	O_3 Water Age
Chl a	<0.001	<0.001	0.007	<0.001	<0.001	0.441	<0.001
Chl b	<0.001	<0.001	0.125	0.002	<0.001	0.322	<0.001
Chl a/Chl b	0.168	0.004	<0.001	0.252	0.123	0.751	0.485
Car	<0.001	<0.001	0.132	0.034	0.068	0.264	0.002
^{A}sat	0.003	0.109	<0.001	0.018	0.380	0.002	0.122
g_s	0.285	<0.001	0.021	0.584	0.543	0.731	0.833
Ci	0.905	<0.001	0.004	0.579	0.753	0.499	0.540
WUE	0.975	<0.001	0.009	0.637	0843	0.509	0.474
Fv'/Fm'	0.021	0.245	<0.001	0.230	0.271	0.870	0.552
qP	0.464	0.207	<0.001	0.402	0.775	0.517	0.966
ΦPSII	0.005	0.114	<0.001	0.463	0.088	0.255	0.759
^{Vc}max	0.004	<0.001	<0.001	0.036	0.312	0.996	0.189
^{J}max	0.034	0.093	<0.001	0.138	0.311	0.550	0.701
^{Vc}max/^{J}max	0.134	0.002	0.588	0.608	0.931	0.705	0.409
^{L}s	0.089	0.227	0.003	0.452	0.191	0.742	0.917

Table: 2 Effects on biomass, growth and senescence-related parameters at the final harvest time, and analysis of variance (P values) of O3, water stress and their interactions. Plants were grown in charcoal-filtered air (CF), non-filtered air (NF) and elevated O3 (E-O3) under well water (WW, irrigated to field capacity) and water stress (RW, 40% irrigation) conditions. Each treatment showed the mean ± SD. Statistically significant differences between treatments are noted with different letters (Tukey test, P < 0.05, n ¼ 3). Statistically significant effects (P< 0.05) are marked in bold.

	WW				RW				O_3	Water	O_3 Water
	CF	NF	E-O_3		CF	NF	E-O_3				
Height (cm)	96.43 ± 11.16 a	91.81 ± 3.11 a	90.07 ± 7.75 a		66.13 ± 11.04 b	60.11 ± 0.77 b	60.00 ± 4.60 b		0.494	<0.001	0.960
Totoal biomass (g)	121.16 ± 3.55 a	112.56 ± 4.36 a	97.32 ± 5.32 b		83.54 ± 3.99 c	80.45 ± 5.07 c	78.19 ± 0.68 c		0.003	<0.001	0.049
Stem diameter (mm)	9.51 ± 0.40 a	8.48 ± 0.42 ab	7.63 ± 0.60 b		6.27 ± 0.30 c	5.75 ± 0.40 c	5.56 ± 0.37 c		0.006	<0.001	0.120
Stem biomass (g)	35.99 ± 2.82 a	33.68 ± 1.58 ab	29.84 ± 1.30 b		21.08 ± 1.28 c	20.53 ± 1.24 c	20.30 ± 0.90 c		0.070	<0.001	0.012
Attached leaves (number)	37.22 ± 2.87 a	33.83 ± 2.47 ab	24.44 ± 1.50 cd		28.78 ± 1.26 bc	25.67 ± 0.67 cd	23.39 ± 1.13 d		0.001	<0.001	0.002
Newly formed leaves	24.78 ± 2.14 a	22.11 ± 1.26 ab	17.89 ± 1.9 bc		18.22 ± 2.8 bc	16.31 ± 2.15 c	15.89 ± 1.17 c		0.033	<0.001	0.321
(number per plant)											
Abscised leaves	1.56 ± 0.19 b	2.33 ± 0.58 b	6.33 ± 0.88 a		1.00 ± 0.33 b	3.56 ± 1.71 ab	5.94 ± 1.58 a		0.001	0.820	0.200
(number per plant)											
Leaves area	0.54 ± 0.05 a	0.53 ± 0.04 a	0.46 ± 0.04 ab		0.36 ± 0.08 b	0.34 ± 0.06 b	0.34 ± 0.05 b		0.370	<0.001	0.312
(m^2 per plant)											
Leaves biomass (g)	52.81 ± 1.57 a	48.37 ± 2.79 a	41.08 ± 3.76 b		36.42 ± 1.77 b	35.84 ± 0.34 b	34.70 ± 1.90 b		0.006	<0.001	0.025
Root biomass (g)	32.36 ± 0.62 a	30.51 ± 0.18 ab	26.40 ± 3.00 abc		26.05 ± 2.68 abc	24.08 ± 3.68 bc	23.19 ± 1.37 c		0.058	0.002	0.389
Root/Shoot	0.37 ± 0.02 b	0.37 ± 0.02 ab	0.37 ± 0.05 ab		0.45 ± 0.04 a	0.43 ± 0.05 ab	0.42 ± 0.03 ab		0.929	0.001	0.350

Source: https://www.sciencedirect.com/science/article/pii/S0269749117305018

Understanding and improving global crop response to ozone pollution (2017)

Annual relative crop yield losses to O_3

	World	North America	European Union	China/East Asia	India/South Asia
Wheat					
AOT40	12.3–15.4%	4.1–11.0%	4.1–12.1%	16.3–19.0%	**26.7–27.6%**
M7	3.9–7.3%	2.6–4.4%	3.3–4.6%	3.3–9.8%	**8.2–13.2%**
Maize AOT40	2.2–2.4%	2.0–2.2%	3.1–3.5%	3.8–4.7%	**2.0–3.4%**
M12	4.1–5.5%	3.6%	5.1–7.9%	7.1–8.0%	**4.0–8.0%**
Soybean AOT40	5.4–8.5%	7.1–12.0%	20.5–23.9%	11.4–20.9%	**3.1–4.7%**
M12	**13.9–15.6%**	**16.9–17.7%**	**27.3–27.4%**	**20.8–24.7%**	**13.2–19.1%**

Estimated relative yield losses for wheat, maize and soybean from two studies combining global atmospheric chemistry models with O3 dose - response relationships (Van Dingenen et al., 2009; Avnery et al., 2011). Yield losses are estimated based on mean exposure (M7: 7-h seasonal O3 mean; M12: 12-h seasonal O3) or seasonal cumulative exposure (AOT40: cumulative exposure to O3 concentrations above 40 ppb).

Source: https://onlinelibrary.wiley.com/doi/epdf/10.1111/tpj.13298

Legacy of historic ozone exposure on plant community and food web structure (2017)

Community structure of the experimental plots during ozone exposure at 0, 90 and 120 ppb and after transplanting under common ecological conditions

	During exposure [a]				After exposure			
	0	**90**	**120**	***P***	**0**	**90**	**120**	***P***
Family richness	14	16	16	ns	11	9	11	**ns**
Legumes	32	31	33	ns	14	15	14	**ns**
Grasses	4	4	3	ns	3	4	3	**ns**
Other herbs	**5**	**8**	**8**	**ns**	**2**	**3**	**3**	**ns**

Values represent Mean number of families (richness) or species in each category during exposure (n = 12) and after exposure (n = 6). ns: not significantly different (P > 0.05) within each row

Mean seedling density in 1 m2 plots established from plant communities. selected under different episodic concentrations of tropospheric ozone (0, 90 and 120 ppb). (2017)

Species	Year 1			Year 2		
	0	**90**	**120**	**0**	**90**	**120**
Spergula arvensis	99.3a	158.3b	129b	104.6a	387b	**216.6c**
Calandrinia ciliata	12.6a	26.3b	40c	11.3a	114.3b	**215.6c**
Medicago lupulina	0	0.3	1	3.3	3.6	**4**
Vicia tetrasperma	0	0	0	1.3	1.3	**0.3**
Rumex crispus	0	0	0	1	0.6	**0.3**
Polygonum persicaria	1a	4b	1a	0	0	**0**
Taraxacum officinale	0.6	1.6	0	1	1	**1**
Digitaria sanguinalis	0.6	0.6	1	0.3	1	**0.3**
Erodium cicutarium	0	0.6	0.6	0.3	1	**0.6**
Solanum sarachoides	0	0.3	0.3	0	0	**0**
Raphanus sativus L.	0.6	0.6	0.3	0	0	**0**
Echinochloa crusgalli	0.3	0.3	0.3	0.3	0	**0.6**
Chenopodium album	0.3	0.3	0	0	0.3	**0.6**
Trifolium repens	0.3	1	0.3	1	0.6	**0.6**
Polygonum argyrocoleon	0.3	0.3	0.3	0	0	**0**
Datura stramonium	1	0.3	1	0	0	**0**
Convolvulus arvensis	0.3	0	0.3	0	0	**0**
Tanacetum vulgare	0	0.3	0.3	0	0	**0**
Oxalis corniculata	1	0.6	0.6	0	0	**0**
Sonchus oleraceus	**0**	**0**	**0**	**0.3**	**0.3**	**0.3**

Values represent mean number (n = 3)
Means followed by different letters within rows for a particular year are significantly different (P = 0.05)

Source: https://doi.org/10.1371/journal.pone.0182796.t003