Title	**Plant phenology, growth and nutritive quality of *Briza maxima*: Responses induced by enhanced ozone atmospheric levels and nitrogen enrichment**
Author	J. Sanz, V. Bermejo, R. Muntifering, I. González-Fernández, B.S. Gimeno, S. Elvira, R. Alonso
Journal	Environmental Pollution, Vol. 159(2)
Abstract	An assessment of the effects of tropospheric ozone (O_3) levels and substrate nitrogen (N) supplementation, singly and in combination, on phenology, growth and nutritive quality of *Briza maxima* was carried out. Two serial experiments were developed in Open-Top Chambers (OTC) using three O3 and three N levels. Increased O_3 exposure did not affect the biomass-related parameters, but enhanced senescence, increased fiber foliar content (especially lignin concentration) and reduced plant life span; these effects were related to senescence acceleration induced by the pollutant. Added N increased plant biomass production and improved nutritive quality by decreasing foliar fiber concentration. Interestingly, the effects of N supplementation depended on meteorological conditions and plant physiological activity. N supplementation counteracted the O_3 -induced senescence but did not modifiy the effects on nutritive quality. Nutritive quality and phenology should be considered in new definitions of the O_3 limits for the protection of herbaceous vegetation.
Year	2011
Pages	423- 430
keywords	

Title	**Effect of ozone exposure on polyamines in Scots pine trees**
Author	Anne Jokela, Tytti Sarjala, Sirkku Manninen, Satu Huttunen
Journal	Environmental and Experimental Botany, Vol. 72(3)
Abstract	Effects of ozone exposure on polyamines in *Pinus sylvestris* L. were studied in a long-term experiment. Ten- to 15-year-old Scots pines were exposed to target ozone levels which began at ambient + 40 ppb in May, decreasing to ambient air only by September for 3 growing seasons. The amount of ozone applied followed the natural pattern of variation in ozone concentrations in Northern Finland. The free, soluble conjugated and insoluble conjugated polyamines were analyzed during the experiment and shortly after termination of exposure as well as at the beginning of the following growing season. A carry-over effect was observed as ozone -induced reduction of free spermidine in the oldest needle year class, which developed during the first exposure season of the experiment. This reduction was observed both after the second and the third ozone exposure season. Conversely, after termination of the experiment, levels of free polyamines increased in the following growing season, and soluble conjugated polyamines decreased in the developing needles. The post-treatment changes in polyamine concentrations are hypothesized to be caused by stress-induced injuries or delayed recovery of metabolic processes rather than protective responses. It is noteworthy that some responses in polyamines were found in the developing needles nine months after terminating the ozone exposure. This suggests that stress-induced

	injuries to older needles affected metabolism of new developing needles. **Research highlights** **Ozone exposure affects the polyamine fluctuation in Scots pine needles.** **Decrease in free polyamine levels indicates a carry-over effect.** **Post-treatment changes in polyamine concentrations occur in new developing needles.**
Year	2011
Pages	448- 454
keywords	

Title	**Cadmium pollution enhanced ozone damage to winter wheat: biochemical and physiological evidences**
Author	Yong Li, Caihong Li, Yanhai Zheng, Guanglei Wu, Tana Wuyun, Hong Xu, Xinhua He, Gaoming Jiang
Journal	Journal of Environmental Sciences, Vol. 23(2)
Abstract	Combined effects of ozone (O_3) and cadmium (Cd) on growth and physiology of winter wheat (*Triticum aestivum* L. cv. JM22) were determined. Wheat plants were grown without or with Cd and exposed to charcoal-filtered air (< 10 ppb O_3) or elevated O_3 (80 ± 5 ppb, 7 hr/day) for 20 days. Results showed that O_3 considerably depressed light saturated net photosynthetic rate (-20%), stomatal conductance (-33%), chlorophyll content (-33%), and total biomass (-29%) without Cd. The corresponding decreases were further enhanced by 45%, 56%, 60% and 59%, respectively with Cd, indicating a synergistic effect of $O_3$and Cd on wheat. Ozone significantly increased the activity of superoxide dismutase (46%), catalase (48%) and peroxidase (56%). However, great increases in malondialdehyde (MDA) content (2.55 folds) and intercellular CO_2 concentration (1.13 folds) were noted in O3+Cd treatment compared to control. Our findings demonstrated that the increased anti-oxidative activities in wheat plants exposed to O3+Cdmight not be enough to overcome the adverse effects of the combination of both pollutants as evidenced by further increase in MDA content, which is an important indicator of lipid peroxidation. Precise prediction model on O3 damages to crop should be conducted to ensure agricultural production security by considering environmental constraints in an agricultural system in peri-urban regions
Year	2011
Pages	255- 265
keywords	antioxidant activity; cadmium; plant growth; ozone stress; *Triticum aestivum* L.

Title	**Plant phenology, growth and nutritive quality of *Briza maxima*: Responses induced by enhanced ozone atmospheric levels and nitrogen enrichment**
Author	J. Sanz, V. Bermejo, R. Muntifering, I. González-Fernández, B.S. Gimeno, S. Elvira, R. Alonso
Journal	Environmental Pollution, Vol.159(2)
Abstract	An assessment of the effects of tropospheric ozone O_3levels and substrate nitrogen (N) supplementation, singly and in combination, on phenology, growth and nutritive quality of *Briza maxima* was carried out. Two serial experiments were developed in Open-Top

	Chambers (OTC) using three $O_3$and three N levels. Increased O_3 exposure did not affect the biomass-related parameters, but enhanced senescence, increased fiber foliar content (especially lignin concentration) and reduced plant life span; these effects were related to senescence acceleration induced by the pollutant. Added N increased plant biomass production and improved nutritive quality by decreasing foliar fiber concentration. Interestingly, the effects of N supplementation depended on meteorological conditions and plant physiological activity. N supplementation counteracted the O_3-induced senescence but did not modifiy the effects on nutritive quality. Nutritive quality and phenology should be considered in new definitions of the O_3 limits for the protection of herbaceous vegetation. **Research highlights** Forage quality (foliar protein and fiber content) and phenology are more O_3-sensitive than growth parameters in the Mediterranean annual grass *Briza maxima*. The effects of N supplementation depended on meteorological conditions and plant physiological activity. Increase in nitrogen supplementation counterbalanced the O_3-induced increase in senescence biomass. Nutritive quality and phenology should be considered in new definitions of the O_3 limits for the protection of natural herbaceous vegetation. Forage quality and phenology are more O_3-sensitive than growth parameters in the Mediterranean annual grass *Briza maxima*.
Year	2011
Pages	423- 430
keywords	Ozone ; Yield; Nutritive quality; Dehesa annual grasslands

Title	**PSII photochemistry and carboxylation efficiency in *Liriodendron tulipifera* under ozone exposure**
Author	Elisa Pellegrini, Alessandra Francini, Giacomo Lorenzini, Cristina Nali
Journal	Environmental and Experimental Botany, Vol. 70(2-3)
Abstract	*Liriodendron tulipifera* is an important forest plant which is commonly used in urban environments as a shade tree. Young plants have been exposed (under controlled conditions) to 120 ppb of O_3 for 45 consecutive days (5 h d-1). The aim of this investigation was to clarify if O_3 limits the physiological performance of *L. tulipifera*. In treated plants, dynamics related to membrane injury, gas exchange and chlorophyll a fluorescence leads to: (i) increase in lipid peroxidation (maximum value of +78% 15 days after the fumigation, compared to controls); (ii) reduction of photosynthetic activity (up to 66% 28 days after the exposure), twinned with a partial stomatal closure and a store of CO_2 in substomatal chambers; (iii) reduction in carboxylation efficiency (-11% at the end of exposure); (iv) damage to PSII, as demonstrated by the increase in the PSII excitation pressure (-57% 28 days after the treatment). On this basis, O_3 should be considered very harmful to *L. tulipifera*, although the reduction of total chlorophylls content and the activation of xanthophyll cycle take place in order to attempt to regulate light absorbed energy limiting oxidative damage. **Research highlights**

	Liriodendron tulipifera is an important forest plant common in urban environments. O_3 is an harmful pollutant to *L. tulipifera*. Visible injury and membrane damage appearance. Impairment of carboxylation efficiency and of PSII photochemistry. Reduction of functional centres with the activation of the xanthophyll is a strategy of defence.
Year	2011
Pages	217- 226
keywords	"Air pollution; Chlorophyll a fluorescence; Oxidative stress; Photosynthesis; Xanthophyll cycle; Urban forest

Title	**Physiological, anatomical and biomass partitioning responses to ozone in the Mediterranean endemic plant *Lamottea dianae***
Author	Vicent Calatayud, Francisco J. García-Breijo, Júlia Cervero, José Reig-Armiñana, María José Sanz
Journal	Ecotoxicology and Environmental Safety, Vol.74(5)
Abstract	Ozone effects on the perennial forb *Lamottea dianae* were studied in an open-top chamber experiment. Ozone was found to induce reductions in CO_2 assimilation and water use efficiency in the leaves of this species. These reductions were mainly related to a decline in the in vivo CO_2 fixation capacity of Rubisco (Vc,max), rather than to stomatal limitations or photoinhibitory damage (Fv:Fm). In addition to chloroplast degeneration, other observed effects were callose accumulation, formation of pectinaceous wart-like cell wall exudates and phloem alterations. Moreover, ozone exposure significantly reduced root dry biomass. The possible relevance of these adverse effects for Mediterranean forbs is commented. These results show that endemic plants can be very sensitive to ozone, suggesting that risks associated with this pollutant should be taken into account for conservation purposes.
Year	2011
Pages	1131- 1138
keywords	Ozone ; Oxidative stress; Photosynthesis; Rubisco; Biomass partitioning; Anatomy; Endemic plants

Title	**The physiological, transcriptional and genetic responses of an ozone- sensitive and anozone tolerant poplar and selected extremes of their F2 progeny**
Author	Nathaniel Robert Street, Tallis Matthew James, Tucker James, Brosché Mikael, Kangasjärvi Jaakko, Broadmeadow Mark, Gail Taylor
Journal	Environmental Pollution, Vol. 159(1)
Abstract	Relatively little is known about the transcriptional response or genetic control of response and adaptation of trees to tropospheric ozone exposure. Such understanding is needed as up to 50% of forests, globally, may be subjected to phytotoxic concentrations of ozone. The physiological, transcriptional and genetic response to ozone was examined in *Populus*

	trichocarpa and *P. deltoids*, which show extreme sensitivity and tolerance to ozone, respectively. Using an inbred F2 mapping population derived from these two species, we mapped quantitative trait loci (QTL) for traits associated with ozone response, examined segregation of the transcriptional response to ozone and co-located genes showing divergent responses between tolerant and sensitive genotypes with QTL. QTL were identified linking detrimental effects of ozone with leaf and biomass traits and differential responses were found for key genes involved in ethylene production and response. Ozone -responsive transcriptional changes and genetic control were studied in Populus plants with contrasting ozone sensitivity.
Year	2011
Pages	45- 54
keywords	Populus; Ozone stress; Microarray; Gene expression; QTL

Title	**Growth of soybean at future tropospheric ozone concentrations decreases canopy evapotranspiration and soil water depletion**
Author	Carl J. Bernacchi, Andrew D.B. Leakey, Bruce A. Kimball, Donald R. Ort
Journal	Environmental Pollution, Volume 159(6)
Abstract	Tropospheric ozone is increasing in many agricultural regions resulting in decreased stomatal conductance and overall biomass of sensitive crop species. These physiological effects of ozone forecast changes in evapotranspiration and thus in the terrestrial hydrological cycle, particularly in intercontinental interiors. Soybean plots were fumigated with ozone to achieve concentrations above ambient levels over five growing seasons in open-air field conditions. Mean season increases in ozone concentrations ($[O_3]$) varied between growing seasons from 22 to 37% above background concentrations. The objective of this experiment was to examine the effects of future $[O_3]$ on crop ecosystem energy fluxes and water use. Elevated $[O_3]$ caused decreases in canopy evapotranspiration resulting in decreased water use by as much as 15% in high ozone years and decreased soil water removal. In addition, ozone treatment resulted in increased sensible heat flux in all years indicative of day-time increase in canopy temperature of up to 0.7 ^{0}C. **Highlights** Globally, tropospheric ozone is currently and will likely continue to increase into the future. We examine the impact of elevated ozone on water use by soybean at the SoyFACE research facility. High ozone grown soybean had reduced rates of evapotranspiration and higher soil moisture. Increases in ozone have the potential to impact the hydrologic cycle where these crops are grown. Soybean grown in elevated concentrations of ozone is shown to evapotranspire less water compared with soybean canopies grown under current atmospheric conditions.
Year	2011
Pages	1464- 1472
keywords	Tropospheric ozone ; Evapotranspiration; Canopy temperature; Soybean; Soil moisture

Title	**Reduced ozone by air filtration consistently improved grain yield in wheat**
Author	Håkan Pleijel
Journal	Environmental Pollution, Vol. 159(4)
Abstract	This study considered effects of reduced [O_3] on wheat yield. Open-top chamber charcoal filtered air treatments were compared with non-filtered treatments for field-grown wheat. 30 experiments meeting requirements were found, representing nine countries in North America, Europe and Asia. 26 experiments reported improved yield and 4 experiments reduced yield by filtration, a significant positive effect. Average yield improvement was 9%. Average daytime [O_3] was reduced by filtration from 35 to 13 nmol mol-1. Filtration efficiency was 63% for O_3 and 56% for SO_2. For NOx it was observed that $NO_2$was reduced and NO increased by filtration. Thus, filters convert NO_2 to NO. Most experiments reported low or very low [SO_2] and [NOx]. Thus, O_3 can be concluded to be the main phytotoxic component in the experiments. Elevated [NO_2] was observed in one experiment. The conclusion is that current [O_3] over large parts of the world adversely affect wheat yield. **Research highlights** Charcoal air filtration consistently improved grain yield in wheat. Ozone was the most important pollutant to reduce wheat yield. Charcoal filters remove O_3, NO_2 and SO_2 but emit NO. Reduced ozone in open-top chamber experiments improved wheat yield over wide geographic areas.
Year	2011
Pages	897- 902
keywords	Charcoal filter; Grain mass; Nitrogen dioxide; Nitric oxide; Ozone ; Sulphur dioxide; Wheat; Yield

Title	**Increased [CO_2] does not compensate for negative effects on yield caused by higher temperature and [O_3] in *Brassica napus L*.**
Author	Georg Frenck, Leon van der Linden, Teis Nørgaard Mikkelsen, Hans Brix, Rikke Bagger Jørgensen
Journal	European Journal of Agronomy, Vol. 35(3)
Abstract	The projected changes of atmospheric composition and associated climatic parameters will challenge the agricultural production in ways, which existing crop populations have not previously experienced. Therefore, understanding the responsiveness to changes of multiple environmental parameters in existing genotypes is vital. In this study, the responses in yield and biomass production of four different cultivars of oilseed rape (*Brassica napus* L.) were tested under five different combinations of increased [CO_2] (700 ppm), temperature (+5 ^{0}C) and [O_3] (+40 ppb). Especially the multifactor treatments are relevant for predictions of the future production, as they mimic the multidimensional environmental changes that are expected within this century. All treatments were given the same amount of water, which

	mimicked future limited water availability e.g. in treatments with elevated temperature. The biomass and yield parameters were found to be significantly cultivar dependent. However, in all cultivars elevated temperature caused a significant reduction in yield parameters, while biomass was not affected significantly. Elevated [CO_2] increased the vegetative biomass significantly, but seed yield was only significantly enhanced in one of the four cultivars studied. Increased [O_3] did not have significant effects on any of the cultivars. In general, the negative effects of a 5 ^{0}C temperature elevation on yield could not be compensated by elevated [CO_2], when simultaneously applied in multifactor treatments. The evaluation of cultivar differences in productivity under elevated [CO_2] in combination with increased temperatures and [O_3] is necessary to derive at a realistic prediction for the future food and biomass production and for the selection of cultivars providing an adaptation potential to environmental change. Our results suggest that future breeding of *B. napus* should be based on old cultivars, since more modern varieties seem to have lower potentials to respond to $CO_2$and thus counteract the detrimental effects of yield reducing environmental factors such as temperature and O_3. **Highlights** We analysed the responses in yield and biomass of four cultivars of oilseed rape. Plants were tested under 5 multi or single factor combinations of increased [CO_2], temperature and [O_3]. The used combinations of factors are new in an effect -experiment with a crop. Results are of interest for predictions of the future primary production.
Year	2011
Pages	127- 134
keywords	Oilseed rape; *Brassica napus*; Crop yield; Carbon dioxide; Temperature; Ozone

Title	**New stomatal flux-based critical levels for ozone effects on vegetation**
Author	Gina Mills, Håkan Pleijel, Sabine Braun, Patrick Büker, Victoria Bermejo, Esperanza Calvo, Helena Danielsson, Lisa Emberson, Ignacio González Fernández, Ludger Grünhage, Harry Harmens, Felicity Hayes, Per-Erik Karlsson, David Simpson
Journal	Atmospheric Environment, Vol. 45(28)
Abstract	The critical levels for ozone effects on vegetation have been reviewed and revised by the LRTAP Convention. Eight new or revised critical levels based on the accumulated stomatal flux of ozone (PODY, the Phytotoxic Ozone Dose above a threshold flux of Y nmol m-2 PLA s-1, where PLA is the projected leaf area) have been agreed. For each receptor, data were combined from experiments conducted under naturally fluctuating environmental conditions in 2–4 countries, resulting in linear dose–response relationships with response variables specific to each receptor ($r2 = 0.49–0.87$, $p < 0.001$ for all). For crops, critical levels were derived for effects on wheat (grain yield, grain mass, and protein yield), potato (tuber yield) and tomato (fruit yield). For forest trees, critical levels were derived for effects on changes in annual increment in whole tree biomass for beech and birch, and Norway spruce. For (semi-)natural vegetation, the critical level for effects on productive and high conservation value perennial grasslands was based on effects on important component species of the genus Trifolium (clover species). These critical levels can be used to assess

	protection against the damaging effects of ozone on food security, important ecosystem services provided by forest trees (roundwood production, C sequestration, soil stability and flood prevention) and the vitality of pasture.
Year	2011
Pages	5064- 5068
keywords	Ozone ; Flux; Critical levels; Food security; Ecosystem services; Trees; Grasslands

Title	**Ozone dose–response relationships for spring oilseed rape and broccoli**
Author	Maarten De Bock, Maarten Op de Beeck, Ludwig De Temmerman, Yves Guisez, Reinhart Ceulemans, Karine Vandermeiren
Journal	Atmospheric Environment, Vol. 45(9)
Abstract	Tropospheric ozone is an important air pollutant with known detrimental effects for several crops. Ozone effects on seed yield, oil percentage, oil yield and 1000 seed weight were examined for spring oilseed rape (*Brassica napus* cv. Ability). For broccoli (*Brassica oleracea* L. cv. Italica cv. Monaco) the effects on fresh marketable weight and total dry weight were studied. Current ozone levels were compared with an increase of 20 and 40 ppb during 8 h per day, over the entire growing season. Oilseed rape seed yield was negatively correlated with ozone dose indices calculated from emergence until harvest. This resulted in an R2 of 0.24 and 0.26 ($p < 0.001$) for the accumulated hourly O_3 exposure over a threshold of 40 ppb (AOT40) and the phytotoxic ozone dose above a threshold of 6 nmol m-2 s-1(POD6) respectively. Estimated critical levels, above which 5% yield reduction is expected, were 3.7 ppm h and 4.4 mmol m-2 respectively. Our results also confirm that a threshold value of 6 nmol s-1 m-2 projected leaf area, as recommended for agricultural crops (UNECE, Mills, 2004), can indeed be applied for spring oilseed rape. The reduction of oilseed rape yield showed the highest correlation with the ozone uptake during the vegetative growth stage: when only the first 47 days after emergence were used to calculate POD6, R2 values increased up to 0.476 or even 0.545 when the first 23 days were excluded. The highest ozone treatments, corresponding to the future ambient level by 2100, led to a reduction of approximately 30% in oilseed rape seed yield in comparison to the current ozone concentrations. Oil percentage was also significantly reduced in response to ozone ($p < 0.001$). As a consequence oil yield was even more severely affected by elevated ozone exposure compared to seed yield: critical levels for oil yield dropped to 3.2 ppm h and 3.9 mmol m^{-2}. For broccoli the applied ozone doses had no effect on yield. **Research highlights** Up to 30% reduction in oilseed rape seed yield can be expected within 100 years. O_3-induced seed yield reduction is most significantly correlated to pre-anthesis uptake. Broccoli yield is unaffected by moderately elevated ozone concentrations.
Year	2011
Pages	1769- 1765
keywords	*Brassica napus*; *Brassica oleracea*; Seed yield; Threshold; AOT40; POD6

Title	**Responses of evergreen and deciduous *Quercus species* to enhanced ozone levels**
Author	Vicent Calatayud, Júlia Cerveró, Esperanza Calvo, Francisco-José García-Breijo, José Reig-Armiñana, María José Sanz
Journal	Environmental Pollution, Vol. 159(1)
Abstract	Plants of one evergreen oak (*Quercus ilex*) and three deciduous oaks (*Q. faginea*, with small leaves; *Q. pyrenaica* and *Q. robur*, with large leaves) were exposed both to filtered air and to enhanced ozone levels in Open-Top Chambers. *Q. faginea* and *Q. pyrenaica* were studied for the first time. Based on visible injury, gas exchange, chlorophyll content and biomass responses, Q. pyrenaica was the most sensitive species, and *Q. ilex* was the most tolerant, followed by *Q. faginea*. Functional leaf traits of the species were related to differences in sensitivity, while accumulated ozone flux via stomata (POD1.6) partly contributed to the observed differences. For risk assessment of Mediterranean vegetation, the diversity of responses detected in this study should be taken into account, applying appropriate critical levels. Ozone tolerance overlapped with leaf traits in four *Quercus species*.
Year	2011
Pages	55- 63
keywords	Ozone ; Functional leaf traits; Stomatal conductance; Photosynthesis; Critical levels; Anatomy

Title	**Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O_3 pollution**
Author	Shiri Avnery, Denise L. Mauzerall, Junfeng Liu, Larry W. Horowitz
Journal	Atmospheric Environment, Vol. 45(13)
Abstract	We examine the potential global risk of increasing surface ozone (O_3) exposure to three key staple crops (soybean, maize, and wheat) in the near future (year 2030) according to two trajectories of O_3pollution: the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES) A2 and B1 storylines, which represent upper- and lower-boundary projections, respectively, of most O_3 precursor emissions in 2030. We use simulated hourly O_3 concentrations from the Model for Ozone and Related Chemical Tracers version 2.4 (MOZART-2), satellite-derived datasets of agricultural production, and field-based concentration: response relationships to calculate crop yield reductions resulting from O_3 exposure. We then calculate the associated crop production losses and their economic value. We compare our results to the estimated impact of O_3 on global agriculture in the year 2000, which we assessed in our companion paper. In the A2 scenario we find global year 2030 yield loss of wheat due to O_3 exposure ranges from 5.4 to 26% (a further reduction in yield of +1.5–10% from year 2000 values), 15–19% for soybean (reduction of +0.9–11%), and 4.4–8.7% for maize (reduction of +2.1–3.2%) depending on the metric used, with total global agricultural losses worth $17–35 billion USD2000 annually (an increase of +$6–17 billion in losses from 2000). Under the B1 scenario, we project less severe but still substantial reductions in yields in 2030: 4.0–17% for wheat (a further decrease in yield of +0.1–1.8% from 2000), 9.5–15% for soybean (decrease of +0.7–1.0%),

	and 2.5–6.0% for maize (decrease of + 0.3–0.5%), with total losses worth $12–21 billion annually (an increase of +$1–3 billion in losses from 2000). Because our analysis uses crop data from the year 2000, which likely underestimates agricultural production in 2030 due to the need to feed a population increasing from approximately 6 to 8 billion people between 2000 and 2030, our calculations of crop production and economic losses are highly conservative. Our results suggest that O_3 pollution poses a growing threat to global food security even under an optimistic scenario of future ozone precursor emissions. Further efforts to reduce surface O_3 concentrations thus provide an excellent opportunity to increase global grain yields without the environmental degradation associated with additional fertilizer application or land cultivation. **Highlights** Surface O_3 will have an increasingly detrimental impact on future crop yields. Yields of wheat, soybean, and maize could be reduced by up to 26% globally in 2030. Global losses up to 17% are possible even in an optimistic scenario of future O_3. Agricultural losses worldwide may be worth $17–35 billion annually by 2030.
Year	2011
Pages	2297- 2309
keywords	Surface ozone; Ozone impacts; Agriculture; Crop loss; Integrated assessment

Title	**Response of hydroponic tomato to daily applications of aqueous ozone via drip irrigation**
Author	Thomas Graham, Ping Zhang, Elisabeth Woyzbun, Michael Dixon
Journal	Scientia Horticulturae, Vol. 129(3)
Abstract	Recycling of greenhouse irrigation water in hydroponic tomato production requires a water remediation process to reduce the risk of pathogen proliferation and the accumulation of other chemical compounds. The dissolution of ozone into bulk irrigation solutions is an effective technology for reducing chemical contaminant and pathogen levels in greenhouse irrigation water. Greenhouse managers utilizing ozonation typically remove residual ozone prior to distribution to the crop. Removal of the active compound in this treatment process has been deemed a prudent measure intended to prevent ozone -based plant damage. This said, although atmospheric ozone has been extensively studied with respect to its phytotoxicity, there are very few studies available on ozone in the aqueous phase in which evidence to support the removal of ozone (on the basis of phytotoxicity) is provided. Furthermore, removal limits the overall efficacy of the treatment as the ozone is not available to treat distribution lines and emitters. The purpose of this study was to determine if aqueous ozone impacts tomato (*Lycopersicon esculentum* Mill. cv Matrix F1) productivity when applied directly to a mineral wool growth substrate via drip irrigation. At the highest aqueous ozone treatment level (3.0 mg L<>-1) significant increases in leaf area, shoot dry matter, and stem thickness were observed. There were no differences across all treatments in terms of net CO_2 assimilation rate, stomatal conductance, internal leaf CO_2 concentration, chlorophyll content index, and fruit production. A qualitative assessment of algae growth on the substrate surface was conducted. Both ozone treatments resulted in a visually discernible reduction in algae prevalence on the substrate surface. The results of

	this study do not support the removal of aqueous ozone (at the concentrations examined) prior to distribution when the solution is applied via drip irrigation in mineral wool hydroponic tomato production. **Highlights** **O_3(aq) in the irrigation solution improved overall tomato plant productivity.** **O_3(aq) has traditionally been removed prior to crop application.** **Removal of O_3 (aq) is not justified (in drip irrigation) on phytotoxicity grounds.** **O_3 (aq) visibly reduced algae on mineral wool surface.** **Solution preparation resulted in enhanced solution oxygenation.**
Year	2011
Pages	464- 471
keywords	Mineral wool; Oxygenation; Phytotoxicity; Algae control; Ozonation

Title	**Diurnal and phenological variations of O_3 and CO_2 fluxes of rice canopy exposed to different O_3 concentrations**
Author	Lei Tong, Xiaoke Wang, Chunmei Geng, Wei Wang, Fei Lu, Wenzhi Song, Hongjie Liu, Baohui Yin, Lihua Sui, Qiong Wang
Journal	Atmospheric Environment, Vol. 45(31)
Abstract	A dynamic chamber system was designed to measure simultaneously the diurnal and phenological canopy ozone (O_3) and carbon dioxide (CO_2) fluxes in the paddy field under different O_3 concentrations (0, 40, 80 and 120 nmol mol^{-1}). On the diurnal timescale, a decreasing trend of canopy O_3 flux was observed from morning to evening and the O_3 flux increased with increasing O_3 concentration, while canopy CO_2 flux generally followed the track of photosynthetic active radiation, with higher values at noon except at the end of the growing season when rice was senescent. The constant CO_2 flux among different O_3 treatments in this experiment suggested that the photosynthesis of the rice canopy was not affected by short-duration (ca. 10 min) O_3 exposure of elevated concentration. The daily mean O_3 and CO_2 fluxes increased with rice growth until the dough stage and the late jointing stage, respectively, then decreased with rice aging. The peak values of O_3 flux appeared later than those of CO_2 flux because the latter was closely synchronized with the leaf area index of the rice canopy. Diurnal mean canopy O_3 flux varied from 18.7 to 43.3 nmol m^{-2} s^{-1}, and nocturnal mean canopy O_3 flux varied from 2.7 to 17.8 nmol m^{-2} $s^{-1}$and from 7.0 to 25.4 nmol m^{-2} s^{-1} for the 40 and 80 nmol mol^{-1} O_3 treatments, respectively. The considerable amount of nocturnal O_3flux indicated a significant contribution of non-stomatal factors to canopy O_3 uptake. The adjusted Jarvis multiplicative models were used and well parameterized to fit the measured O_3 and CO_2 fluxes of our rice cultivar from environmental variables. Although more validation work is needed, the present results suggest that the models can be considered as a tool for canopy flux predictions in the paddy field. **Highlights** O_3 flux of rice canopy correlates with O_3 concentration positively. Short-duration O_3exposure has little influence on CO_2 flux of rice canopy. Phenological variation of leaf area dominates that of O_3 flux.

	Non-stomatal O_3 removal is remarkable for rice canopy. Adjusted Jarvis models were well parameterized to fit the measured fluxes of rice canopy.
Year	2011
Pages	5621- 5631
keywords	Chamber; Ozone ; Carbon dioxide; Flux; *Oryza sativa*; Jarvis model