Ozone Damages to Italian Crops: Environmental Constraints

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Abstract

The main environmental features of Italian cropping systems are described with particular emphasis on their effects on crop responses to ozone pollution.

High ozone levels have been recorded all over Italy and daily patterns show, at nighttimes, strong decreases in plain areas, while ozone levels remain high in hilly areas. In the latter sites, therefore, the contribution of nocturnal stomatal conductance (g_{sto}) to ozone uptake should be further studied. It is well known that summer drought and soil salinity reduce the soil water potential, thus causing g_{sto} to decrease. These are likely to be the most important factors reducing crop gas-exchange and yield under environmental conditions occurring in Italy. However, the stress-induced reduction of g_{sto} also restricts ozone uptake and, consequently, its potential damage. In Southern Italy, gas-exchange limitations have been also measured in irrigated crops between two successive irrigations. Finally, the effect of water stagnation, which often occurs in clay soils of southern Italy, should be not underestimated. In these soils, in fact, root anoxia will cause stomatal closure and, consequently, will also interfere with ozone uptake and damage.

Key-words: Italian environment, abiotic stresses, ozone, drought, salinity.

1. Introduction

Atmospheric pollution can cause severe losses of crop yields, and ozone is considered the most important component of polluted air in Mediterranean environments (Lorenzini, 1999). Ozone is considered the most important pollutant of rural areas where, unlike the cities, there are few other pollutants (i.e. NO) that react with ozone to reduce its concentration (Hayes et al., 2007). Prediction analyses also estimate that, during this Century, a severe increase of ozone levels in central and southern Europe will occur (Sitch et al., 2007).

This pollutant is well known as the most harmful for vegetation (Heck et al., 1982), but only in the last decade its effects on crops have become a major concern in Europe (Fuhrer et al., 1997) and in Italy (Nali et al., 2002; Fagnano et al., 2008).

Since ozone penetration into plant tissues occurs mainly through stomata, all the factors that reduce stomatal conductance could also reduce ozone uptake by leaves and the consequent damages to crops (Guderian, 1985; Darrall, 1989; Iqbal et al., 1996).

The Italian (16/5/96 DM) and European (directive 2002/3/CE) legislations refer to a concentration-based critical level for calculating the thresholds for ozone damages to vegetation. However, previous studies carried out in Italy (Ferretti et al., 2007) reported that ozone concentration was poorly correlated with yield loss, even though the former was often much higher than the recommended threshold. Therefore it is necessary to revise the European legislation by adopting flux-based models, able to estimate the reduction of plant stomatal conductance, and ozone uptake, caused by environmental constraints.

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In this context, the aim of this paper is to present the environmental conditions of Italian cropping systems, with particular attention to those features that can modify crop ozone uptake.

2. Ozone pollution

In Italy, ozone levels are particularly high (Tab. 1) and AOT40 (the hourly concentrations exceeding the 40 ppb threshold cumulated over a 90 days period) reaches values much higher than the 3000 ppb h critical threshold, without differences between northern and southern locations (Manes et al., 2002).

Daily patterns of ozone are quite different depending on site elevation. In plain areas, ozone concentration peaks are recorded in the afternoon and the decreasing phase occurs during the evening-night hours to reach the minimum values at dawn (Fig. 1). Such trend correlates to air temperature more than to solar radiation (Fagnano, 1995).

On the contrary, on hills and mountains the decreasing phases of ozone concentration is strongly reduced, thus determining high ozone values during nighttimes and a small amplitude of the daily cycles (Fig. 2). This feature has been detected both in hilly areas > 700 m a.s.l. (Forlani et al., 2005) and in mountain areas (Vecchi and Valli, 1999).

The night ozone level is often overlooked by current ozone uptake models, although in the elevated sites of Italy it may significantly contribute to reach a damage concentration threshold.

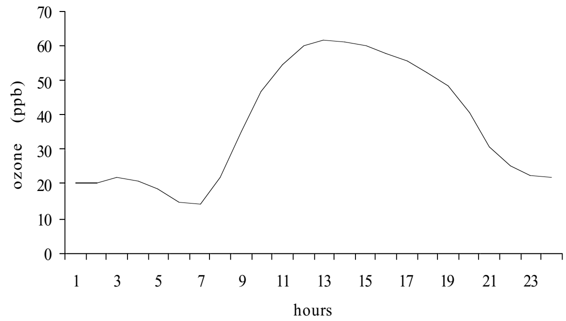

Figure 1. Daily trend of ozone during summer (June-August): mean values 2000-2004 recorded in Portici, NA, 30 m a.s.l.

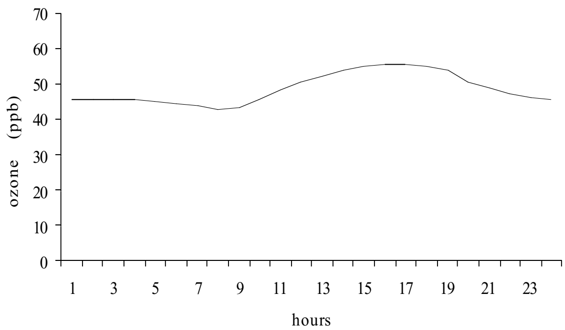

Figure 2. Daily trend of ozone during summer (June-August): mean values 2000-2002 recorded in S. Angelo dei Lombardi, AV, 700 m a.s.l.

The relationship between ozone pollution, stomatal conductance and ozone uptake by plants, however, is not unequivocal Schenone et

Table 1. Ozone levels in different Italian locations.

Site	Coordinates	Elevation	Year	O_3max	AOT_{40}	Period	Days	References
Isola serafini	45°05'N; 9°56'E	40	2000	68.8	20.0	17/5-6/9	112	Manes et al., 2002
Roma	41°54'N; 12°31'E	20	2000	60.3	13.5	19/5-8/9	112	Manes et al., 2002
Portici	40°49'N; 14°20'E	30	2000	76.8	22.9	19/5-8/9	112	Manes et al., 2002
S.Angelo dei L.	40°55'N; 15°10'E	700	2000	67.3	23.9	15/5-4/9	112	Manes et al., 2002
Bellizzi	40°37'N; 14°56'E	30	2000	56.8	7.5	12/5-1/9	112	Manes et al., 2002
Portici	40°49'N; 14°20'E	30	2001	64.2	14.8	25/6-15/10	112	Forlani et al., 2005
S.Angelo dei L.	40°55'N; 15°10'E	700	2001	53.7	8.6	30/6-14/10	106	Forlani et al., 2005
Bellizzi	40°37'N; 14°56'E	30	2001	55.8	12.5	20/6-17/10	119	Forlani et al., 2005
Portici	40°49'N; 14°20'E	30	2002	52.1	7.4	25/6-15/10	112	Forlani et al., 2005
S.Angelo dei L.	40°55'N; 15°10'E	700	2002	49.4	6.6	27/6-16/10	111	Forlani et al., 2005
Bellizzi	40°37'N; 14°56'E	30	2002	52.7	4.3	20/6-17/10	119	Forlani et al., 2005
Portici	40°49'N; 14°20'E	30	2003	67.4	12.0	10/5-25/7	57	unpublished data
Portici	40°49'N; 14°20'E	30	2004	61.6	10.0	10/5-25/7	57	Merola and Fagnano, 2006
Bellizzi	40°37'N; 14°56'E	30	2005	62.0	14.5	20/6-17/9	89	Fagnano et al., 2007
Bellizzi	40°37'N; 14°56'E	30	2006	59.2	10.1	4/5-2/8	90	Fagnano et al., 2007

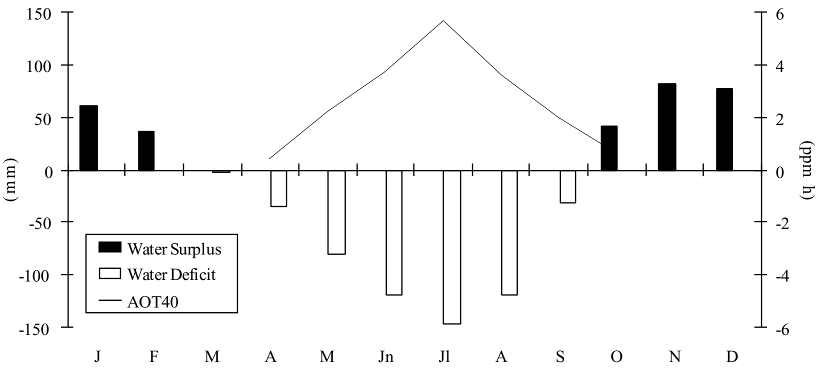

Figure 3. Monthly values of water balance (1920-1986) and AOT40 (1996-2003) in Naples.

al., 1994). High O_3 levels during daytime generally causes a reduction in stomatal conductance (Fagnano and Merola, 2007) as demonstrated by the significant correlation ($R^2 = 0.67$) between AOT40 and g_{sto} reduction (Bou Jaoudé et al., 2008a).

Nevertheless, high ozone levels may also lead to a slow stomatal response to light and, consequently, to an incomplete stomatal closure during nighttimes, which may increase O_3 fluxes into the plant (Paoletti, 2005; Grulke et al., 2007). In addition, it should also be considered that the detoxification capacity of plants is less efficient during the night (Musselman and Minnick, 2000).

3. Climatic conditions

Among the other environmental factors that can modify plant responses to ozone, soil water deficit is the most common all over Italy.

Based on the data of Italian meteorological stations (2000-2004), a strong year variability can be noted (Tab. 2). The mean air temperature ranges from 12.0 to 22.3 °C, the potential evapotranspiration (Hargreaves et al., 1985) ranges from 841 to 1047 mm per year and total rainfall ranges from 575 mm to 961 mm. Therefore, the year water balance (rainfall *minus* ETP) ranges from positive values in the hilly station of Monte Rufeno, to negative ones in all the others, with a negative peak (-473 mm) in Rome and a very high variation coefficient (CV = 92%). In contrast, the summer water deficit is more spread and homogeneous throughout Italy, ranging from -265 mm in the hilly station (Monte Rufeno) to -411 mm in Rome, with a lower variation coefficient (CV = 14%).

Therefore, the Italian vegetation grows from June to August under severe water limitation, also in the higher elevation sites, with rainfalls that fulfill less than half of the evapotranspirative demand (from 40% to 20%).

The climatic data of Naples (Fig. 3) indicate a strong correlation between the monthly water

Table 2. Meteorological parameters of some Italian stations (mean values of 200-2004).

Location	Latitude	Elevation	Year conditions				Summer conditions (Jun-Aug)	
			Mean Temperature	Rain	ETo	Rain-ETo	Rain-ETo	Rain: ETo
	(°N)	(m a.s.l.)	(°C)	(mm year-1)			(mm)	(%)
Grugliasco	45°04’	293	12.0	746	1014	-268	-325	33
Sala Baganza	44°43’	200	12.9	856	881	- 25	-265	38
Colognole	42°52’	30	16.3	669	888	-219	-307	21
M.te Rufeno	42°49’	675	12.0	961	913	+ 47	-304	30
Roma	41°44’	18	21.4	575	1047	-473	-411	13
Portici	40°49’	70	21.8	621	841	-221	-306	18
Bellizzi	40°12’	30	22.3	831	1003	-138	-352	18

deficit and the monthly cumulated ozone concentrations (Fig. 4).

Several experiments demonstrated that water shortage reduces stomatal conductance and limits O_3 uptake and damage (Fagnano and Merola, 2007; Bou Jaoudé et al., 2008b; Maggio and Fagnano, 2008).

Italian climate is also characterized by 5-6 months of water surplus (rainfall > evapotranspiration), that could reduce oxygen availability for the roots in clay soils (Fagnano and Maggio, 2008). This was found to reduce chlorophyll content (Ashraf and Mehmood, 1990) and g_{sto} from 1 to 0.1 mol H_2O m^{-2} s^{-1} (Issarakraisila et al., 2007) in Brassica species. Therefore also waterlogging from October to March may reduce ozone uptake by modifying crop responses to this pollutant in environments, such as the Mediterranean areas, which have high ozone levels also during autumn and spring .

4. Soil-water quality

Another environmental problem of Mediterranean areas is the salinization of both soils and watertable due to saltwater intrusions and inadequate irrigation management. An increase of saltwater intrusion is predicted in the future because of increasingly greater water consumption for irrigation and potable uses, coupled with a decreased rain water infiltration. This scenario may be worsened by further modifications of

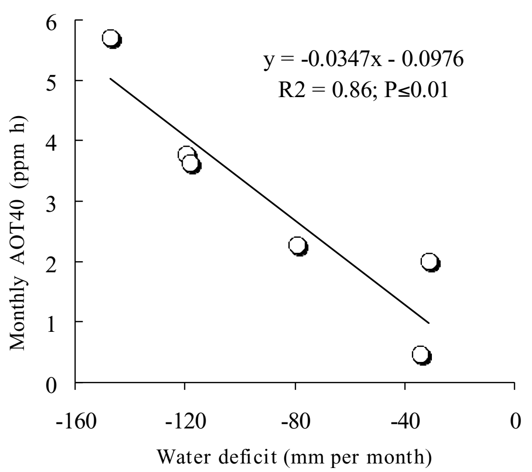

Figure 4. Correlation between monthly AOT40 and water deficit.

the rainfall patterns that are likely to occur in Mediterranean areas according to current climate change predictions (Monteleone, 2006).

Some estimates report that half of irrigated land shows more or less serious problems of salinization (about 1000 M ha) and that salinization of water tables and soils affects 2 % of the total cultivated land (equal to 16 million hectares) in the Mediterranean Basin (Fagnano and Quaglietta-Chiarandà, 2004), mainly concentrated in Egypt, Algeria and Turkey (Hamdy, 2002).

In Italy, the progressive salinization of coastal plains is reported in the Po Valley (Giardini, pers. comm.), Southern Puglia and Sicily, but this may be an underestimate of the actual phenomenon because there is not a systematic monitoring of deep waters (APAT, 2002). Some studies estimated problems of salification in about 450.000 ha in Italian cropland and reported the occurrence of saline springs in the Campania region (ECe from 3.9 to 11.9 dS m^{-1}, Postiglione, 2002), in Puglia (ECe from 1.1 to 4.2 dS m^{-1}, Caliandro et al., 1997) ed in Sicily (ECe until to 6 dS m^{-1}, Fierotti et al., 1999).

Salinity of irrigation water is a well known problem because it represents a strong environmental emergency with heavy social and economic impacts in many countries, where even non-conventional waters, such as salt water, drainage water or waste water are used for irrigation purpose (Bouwer, 2000; Pereira et al., 2002).

For instance, in some Mediterranean areas, such as North Africa, characterized by high evapotranspirative demand, low leaching rainfalls and frequent seawater intrusions in watertables, saline waters (ECe > 1 dS m^{-1}) are normally used for irrigation (Katerji, 2002).

The effects of soil salification on the physiology of most crops in relation to ozone damages have also been documented (Maggio et al., 2007; Maggio and Fagnano, 2008). Salinization reduces the soil water potential and will cause water stress. Crops respond to such water limitation by decreasing leaf gas-exchange, to counteract irreversible water loss and tissue dehydration. In several experiments, g_{sto} has been reduced by saline stress from 15 to 72% depending on species considered, the soil texture and the stress magnitude (De Pascale et al., 1995, 2003; van Hoorn et al., 1993; Katerji et al., 1996, 1997, 1998; Maggio et al., 2005).

The promoting effect of the aforementioned environmental constraints on the accumulation of antioxidants should also be considered, since these stress-metabolites may further increase the ozone detoxification capacity of Mediterranean crops (Nali et al., 2004; Maggio and Fagnano, 2008).

5. Conclusions

The environmental conditions of Italian cropping systems are characterized by several stressors that reduce gas exchange and yield.

High ozone pollution levels in rural areas, water deficit during spring-summer periods and irrigation with saline water are known to be the main limiting factors for crop growth and future scenarios predict further environmental constraints for Italian cropping systems.

Nevertheless, all these stressors may reduce stomatal conductance and thus plant ozone uptake. Therefore crop responses to this harmful pollutant could be strongly modified by other environmental stress responses that typically overlap to critical periods of plant exposure to ozone.

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