Title:	Assessment of crop yield losses in Punjab and Haryana using 2 years of continuous in situ ozone measurements
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Abstract:	In this study we use a high-quality data set of in situ ozone measurements at a suburban site called Mohali in the state of Punjab to estimate ozone-related crop yield losses for wheat, rice, cotton and maize for Punjab and the neighbouring state Haryana for the years 2011-2013. We intercompare crop yield loss estimates according to different exposure metrics, such as AOT40 (accumulated ozone exposure over a threshold of 40) and M7 (mean 7-hour ozone mixing ratio from 09:00 to 15:59), for the two major crop growing seasons of kharif (June-October) and rabi (November-April) and establish a new crop-yield-exposure relationship for southern Asian wheat, maize and rice cultivars. These are a factor of 2 more sensitive to ozone-induced crop yield losses compared to their European and American counterparts. Relative yield losses based on the AOT40 metrics ranged from 27 to 41 % for wheat, 21 to 26 % for rice, 3 to 5 % for maize and 47 to 58 % for cotton. Crop production losses for wheat amounted to 20.8 ± 10.4 million t in the fiscal year of 2012-2013 and 10.3 ± 4.7 million t in the fiscal year of 2013-2014 for Punjab and Haryana taken together. Crop production losses for rice totalled 5.4 ± 1.2 million t in the fiscal year of 2012-2013 and 3.2 ± 0.8 million t in the year 2013-2014 for Punjab and Haryana taken together. The Indian National Food Security Ordinance entitles ~ 820 million of India's poor to purchase about 60 kg of rice or wheat per person annually at subsidized rates. The scheme requires 27.6 Mt of wheat and 33.6 Mt of rice per year. The mitigation of ozone-related crop production losses in Punjab and Haryana alone could provide > 50 % of the wheat and ~ 10 % of the rice required for the scheme. The total economic cost losses in Punjab and Haryana amounted to USD 6.5 ± 2.2 billion in the fiscal year of 2012-2013 and USD 3.7 ± 1.2 billion in the fiscal year of 2013-2014. This economic loss estimate represents a very conservative lower limit based on the minimum support price of the crop, which is lower than the actual production costs. The upper limit for ozone-related crop yield losses in all of India currently amounts to 3.5-20 % of India's GDP. The mitigation of high surface ozone would require relatively little investment in comparison to the economic losses incurred presently. Therefore, ozone mitigation can yield massive benefits in terms of ensuring food security and boosting the economy. The co-benefits of ozone mitigation also include a decrease in the ozone-related mortality and morbidity and a reduction of the ozone-induced warming in the lower troposphere.

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