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Research Article

Effect of air pollutants on physiological parameters and yield attributes of paddy and wheat crops in Faridabad region, India

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Abstract
Air pollution is one of the major problems in the Delhi NCR region due to industrial emissions, traffic congestion, population growth and rapid development. Air pollutants deteriorate the environment, human health, plants and crops. This study focuses on the physiological parameters and yield attributes of paddy and wheat crops in the vicinity of a gas-based national thermal power plant (NTPC) located in Faridabad. Ten sites were selected, including the control site within a 10 km aerial distance from the exhaust chimney stack of the power plant. Major air pollutants, such as NOx, SOx, O_3, and $PM_{10,}$ were monitored using Central Pollution Control Board (CPCB) guidelines. The air quality index (AQI) was moderately polluted at the sampling site, while good air quality was observed at the control site. The results showed that the photosynthetic rates were reduced to 46% in paddies and 48% in wheat crops. In the vegetative growth stage of paddies and wheat crops, the stomatal conductance of paddies decreased to 0.11 mmol $m^{-2}s^{-}1$ compared to 0.19 mmol $m^{-2}s^{-}1$ at the control site. The transpiration rate ranged from 0.6 to 7.7 μmol/m^2/s in paddies and 1.2 to 9.8 μmol/m^2/s in wheat crops. The R^2 value ranged from 0.702 to 0.985, which shows a strong impact of the air quality index on the physiological parameters of crops. The yield reduction due to air pollution in paddies was 11.6%, and in wheat crops, it was 14.8%. This study also provides an inventory of air pollutants in Faridabad region and their subsequent impacts on crops.

Keywords: Air, Paddy, Photosynthetic Rate, Wheat, Yield

INTRODUCTION

Rice and wheat crops are the staple foods of India. The low supply and poor quality of these crops may affect billions of people in the country. Simultaneously, these crops provide food security and livelihood to millions of rural populations (Gupta and Seth, 2007). The rapid growth of the world population would cause an increase in the demand for rice, and by 2025, the production of paddies needs to be increased by 60% of what is currently produced to meet the demand for food (Gupta et al., 2017). Increased urbanization, industrialization and transportation have worsened the condition of air quality in India (Mina et al., 2013). Air pollution has adverse effects on paddies and wheat crops, as it may affect the quality and quality of the yield (Ramya *et al.,* 2021; Mina *et al.,* 2021). Plants are affected by pollutants either directly through leaf exposure or indirectly via acidification of soil through wet deposition. Due to continuous exposure to pollutants, plants show changes in physiological parameters, and further accumulation may also result in visible injuries (Braun *et al.,* 2017). Shi *et al.* (2009) found that ozone enhancement in an open air chamber resulted in a reduction in plant height, number of mainstems, and number of spikelets per panicle in paddies. Kuddus *et al.* (2011) reported that air pollution may result in stomatal damage, necrosis and chlorosis, changes in enzymatic reactions and permeability of the cell membrane and alterations in photosynthetic activity due to reductions in chlorophyll content and thereby fluctuations in the rate of transpiration and respiration. Burney and Ramanathan (2014) reported that the effect of air pollution on paddies and wheat crops was greater than the effect of meteorological factors (precipitation, temperature, etc.). Malav *et al.* (2017) studied the effect of air pollution from coal-based thermal power plants on paddies and wheat crops and reported yield reductions of up to 14%. The photosynthetic rate and stomatal conductance in the vegetative and reproductive stages of paddies and its yield were observed to decrease even at moderate air pollution indices (Aziz *et al.,* 2019). Increased surface ozone pollution causes a reduction in the yield of wheat crops. Ren et al. (2020) found that ground level ozone in China has caused yield reductions of paddy crops by 9% and wheat crops by 20%. Zhang *et al.* (2020) conducted an experiment to observe changes in the growth of paddies and wheat under elevated ozone concentrations and concluded that the photosynthetic rate and shoot biomass of paddy and wheat plants were significantly decreased. In view of the above studies, the present study was undertaken to assess the pollution level at marked sites, physiological changes, transpiration rate, stomatal conductance and yield of paddy and wheat crops at vegetative, reproductive and maturity phases in the vicinity of a gas-based power plant in the Faridabad district.

MATERIALS AND METHODS

Study area

The study area was the National Thermal Power Corporation (NTPC) commissioned gas-based thermal power plant at Mujedi Village, District Faridabad (Haryana) (28.4089° N latitude, 77.3178° E longitude; area 742.9 km^2). Nine sampling sites, including one control site selected within a 10 km radius of the exhaust chimney stack of the power plant, Mujedi, Faridpur, Sadupura, Bhuapur, Tigaon, Mandhawali, Gharora, Badraula, Khera and Ghazipuras, are shown in Figure 1. The gas-based power plant is located in Mujedi village, and Ghazipur is taken as the control site. The distance of the control site is 9 km away from the power plant. The sites are selected in the north, east and south directions since the direction of the wind is westward and there is a national highway running along the westside of the power plant. The major crops grown around this region are paddy and wheat crops.

Air quality analysis

Major air pollutants, such as NO_x, SO_x, O_3 and $PM_{10,}$ were monitored at ten sites. In each month, 24-hour sampling was performed during the growth of paddies (May-July) and wheat crops (November to January).

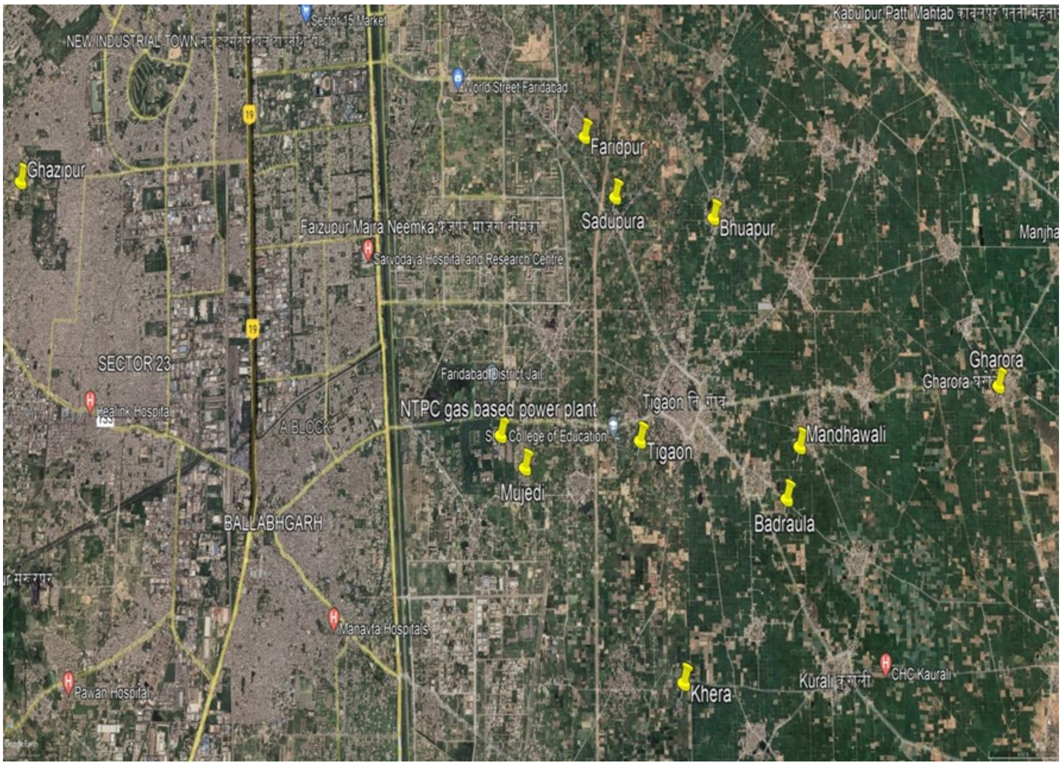

Fig. 1. *Map of ten study sites near National Thermal Power Corporation (NTPC) commissioned gas-based thermal power plant at Mujedi Village, District Faridabad*

The sampling and analysis of these air pollutants was performed using CPCB Guidelines (Central Pollution Ccontrol Board, 2011). The air pollutant samples were collected using a Respirable Dust Sampler (Envirotech APM460BL). NO_x was analysed by the Jacob and Hochheiser method (Jacob and Hochheiser, 1958), SO_x by the West and Gaeke method (West and Gaeke,1956), O_3 by the chemical method) and PM_{10} by the gravimetric method (Central Pollution Control Board, 2011). The different categories of AQI values are mentioned in Table 1. National Ambient Air Quality Standard (NAAQS) for air pollutants are given in Table 2. The Air Quality Index (AQI) represents the single value of air quality as a whole and was calculated using NO_x, ozone and PM_{10} (Rao and Rao, 1998).

$AQI = 1/3 (O_3/80 + NO_x/80 + PM_{10}/100) \times 100$

where (O_3), (NO_x) and (PM_{10}) represent the individual concentrations (µg/m3).

Crop parameters

Physiological parameters, such as the photosynthetic rate, stomatal conductance and transpiration rate of the paddy wheat crop, were measured by an infrared gas analyser (Model No. LI-6400-40, LICOR Inc. USA) between 9a.m. to 6p.m. (Malav et al., 2017). The measurements were taken in vegetative, reproductive and maturity stages of paddy and wheat crops. In the maturity stage of paddy and wheat crops, the yield attributes of both crops were calculated using a weight of 1000 grains (gms) divided by area (sq.m.) (Singh et al.,2014).

Statistical analysis

Statistical analysis was performed using Microsoft Excel 2007. The data are presented as the mean ± standard deviation of triplicate values. Regression analysis (R^2) was performed to identify the impacts of independent variables, i.e., the air quality index (AQI), on dependent variables, including crop physiological parameters, photosynthetic rate, stomatal conductance, transpiration rate and yield.

Table 1. Different categories of AQI value

AQI value	Level of air quality
0-50	Good
51-100	Satisfactory
101-200	Moderately polluted
201-300	Poor
301-400	Very poor
401-500	Severe

Table 2. National Ambient Air Quality Standard (NAAQS) for air pollutants.

S. No.	Air Pollutant	NAAQS (µg/m^3)
1.	O_3	100
2.	NO_x	80
3.	SO_x	80
3.	Particulate Matter (PM_{10})	100

RESULTS AND DISCUSSION

Ambient air quality

The concentrations of NO_x, SO_x, ozone and PM10 at the nine sampling sites and the control site in each month are given in Table 3. The maximum value of NOx was 109.5 µg/m^3 in Mujedi, while its minimum value was 31.1 µg/m^3 during January at the control site. In Mujedi, Tigaon and Mandhawali, the concentration of NO_x exceeded the standard permissible limit of 80 µg/m^3. For SO_x, the maximum value of 48.9 µg/m^3 was found in Mujedi during December month, while its minimum value was 17.5 µg/m^3 during December month at the control site. The concentration of SO_x at all the sites was within the standard permissible limit of 80 µg/m^3. O'Shea et al., 2016 reported that the mean concentrations of SO_x and NO_x in Delhi were 25 µg/m^3 and 75 µg/m^3, respectively, which is similar to our findings. During May, the highest value of ozone in Mujedi was 86.4 µg/m^3, while the lowest value was 31.3 µg/m^{3}at the control site. PM_{10} concentrations were higher than the permissible limit of 100 µg/m^{3}at all locations. The highest concentration of PM_{10} was recorded at Mujedi (286.5 µg/m^3), whereas the lowest concentration was reported at the control site (132.5 µg/m^3). The concentrations of ozone in Muejdi and Tigaon exceeded the standard permissible limit of 80 µg/m^3. Hora et al. (2018) reported that the maximum concentration of ozone in Delhi was 81.1 µg/m^{3,} which is similar to our ozone concentration in Faridabad. At the sampling sites, the air quality index (AQI) ranged from moderately polluted to satisfactory air quality, whereas the control site had good air quality (Table 4). Satisfactory air quality was observed in Gharora, Badraula and Khera in some of the months, and moderate pollution air quality was found in the remaining six sites in all months.

Photosynthetic rate

Photosynthesis is the most stress-sensitive activity in plants, as it is hampered by stress before any other symptom appears (Anoob et al. 2017). The photosynthetic rate (µmolCO_2/m^2/s) invegetative, reproductive and maturity stages of paddy wheat crops at the nine sampling sites and control sites are given in Table 5. In the vegetative stage, the minimum value of the photosynthetic rate for paddies was 5.7 µmolCO_2/m^2/s, while the maximum value was 9.5 µmolCO_2/m^2/s at the control site. In the reproductive stage of the wheat crop, the photosynthetic rate was reduced up to 7.9 µmol.CO_2/m^2/s in Mujedi as compared to 13.9 µmolCO_2/m^2/s at the control site. In the maturity stage, the minimum

Table 3. Concentrations of NO_x, SO_x, PM_{10} and ozone (µg/m^3) at ten different sites of Faridabad in 2016

Sites	Paddy			Wheat		
	May Vegetative	**Jun Reproductive**	**Jul Maturity**	**Nov Vegetative**	**Dec Reproductive**	**Jan Maturity**
NOx (µg/m^3)						
Mujedi	85.3	95.1	63.4	79.6	92.7	109.5
Faridpur	70.9	61.5	45.2	62.2	78.2	88.4
Sadupura	71.3	68.4	51.7	64.7	81.3	99.3
Bhuapur	76.2	72.1	53.4	70.9	84.4	105.8
Tigaon	81.5	84.5	61.8	75.1	90.5	94.7
Mandhawali	80.4	78.7	56.7	74.3	85.2	91.2
Gharora	63.6	58.2	44.9	59.8	76.3	72.4
Badraula	61.4	55.7	41.6	51.3	63.4	81.5
Khera	41.8	44.2	32.8	48.2	58.7	66.7
Ghazipur (control site)	18.7	20.6	11.4	20.2	28.5	31.1
Mean	62.9	63.9	46.3	60.6	73.9	84.1
S.D.	20.5	21.3	15.4	17.5	19.3	23.1
SO_x(µg/m^3)						
Mujedi	41.3	43.5	38.6	46.8	48.9	45.1
Faridpur	31.2	31.6	24.2	40.8	39.5	37.2
Sadupura	34.9	35.8	28.6	41.2	40.6	41.3
Bhuapur	35.4	37.2	30.9	43.9	43.1	42.8
Tigaon	38.7	42.6	35.3	46.1	45.2	40.4
Mandhawali	38.2	40.9	31.2	45.2	44.8	38.5
Gharora	28.6	30.4	22.3	38.6	39.2	31.2
Badraula	25.2	28.8	21.8	35.2	36.8	34.9
Khera	24.8	25.1	21	32.3	35.4	28.6
Ghazipur (control site)	12.3	15.2	12.5	18.9	17.5	16.4
Mean	31.1	33.1	26.6	38.	39.1	35.6
S.D.	8.7	8.8	7.7	8.5	8.6	8.5
PM_{10} (µg/m^3)						
Mujedi	279.4	284.2	271.4	280.2	286.5	282.5
Faridpur	243.5	240.2	239.3	243.8	257.6	249.2
Sadupura	257.2	251.8	247.2	257.5	262.8	263.8
Bhuapur	263.5	255.8	254.3	262.8	269.3	271.5
Tigaon	272.6	276.5	265.6	274.6	282.1	260.2
Mandhawali	268.6	269.3	262.8	269.3	275.2	254.3
Gharora	238.7	231.9	224.8	228.2	250.9	236.2
Badraula	232.4	226.5	220.2	220.5	243.5	241.6
Khera	218.9	213.7	208.6	209.8	238.9	224.3
Ghazipur (control site)	156.4	148.1	141.7	136.2	140.8	132.5
Mean	243.1	239.8	233.6	238.3	250.8	241.6
S.D.	36.0	39.3	38.4	43.1	41.7	42.0
Ozone (µg/m^3)						
Mujedi	86.4	82.5	49.7	61.2	60.3	69.6
Faridpur	59.2	56.7	21.2	44.3	41.2	34.5
Sadupura	64.8	59.3	23.8	49.6	46.7	51.8
Bhuapur	69.7	68.4	27.9	50.5	50.3	55.3
Tigaon	81.2	75.8	42.3	58.8	53.2	46.2
Mandhawali	72.5	70.2	31.6	53.2	52.4	38.3
Gharora	55.1	48.1	19.4	41.2	37.5	25.2
Badraula	48.6	43.2	17.6	39.5	33.8	29.1
Khera	45.3	41.5	16.2	35.2	28.6	18.7
Ghazipur (control site)	31.3	32.8	11.3	21.8	25.3	12.5
Mean	61.4	57.8	26.1	45.5	42.9	38.1
S.D.	17.0	16.3	12.1	11.8	11.5	17.7

Table 4. AQI values at ten different sites of the area in 2016

Sites	AQI- May	AQI- June	AQI- July	AQI- Nov	AQI- Dec	AQI- Jan
Mujedi	157 (Moderate)	159 (Moderate)	140 (Moderate)	135 (Moderate)	139 (Moderate)	143 (Moderate)
Faridpur	129 (Moderate)	121 (Moderate)	111 (Moderate)	107 (Moderate)	112 (Moderate)	111 (Moderate)
Sadupura	135 (Moderate)	129 (Moderate)	119 (Moderate)	115 (Moderate)	117 (Moderate)	127 (Moderate)
Bhuapur	141 (Moderate)	135 (Moderate)	123 (Moderate)	122 (Moderate)	122 (Moderate)	133 (Moderate)
Tigaon	152 (Moderate)	149 (Moderate)	135 (Moderate)	130 (Moderate)	134 (Moderate)	122 (Moderate)
Mandhawali	147 (Moderate)	143 (Moderate)	128 (Moderate)	126 (Moderate)	125 (Moderate)	116 (Moderate)
Gharora	123 (Moderate)	114 (Moderate)	100 (Satisfactory)	98 (Satisfactory)	108 (Moderate)	97 (Satisfactory)
Badraula	118 (Moderate)	107 (Moderate)	97 (Satisfactory)	90 (Satisfactory)	99 (Satisfactory)	104 (Moderate)
Khera	99 (Satisfactory)	94 (Satisfactory)	86 (Satisfactory)	82 (Satisfactory)	94 (Satisfactory)	89 (Satisfactory)
Ghazipur (control site)	41 (Good)	37 (Good)	29 (Good)	28 (Good)	33 (Good)	30 (Good)

photosynthetic rate of paddy and wheat crops was 2.1 μmol $CO_2/m^2/s$ in Mujedi village, while the maximum photosynthetic rate was observed at the control site at 3.9 μmol $CO_2/m^2/s$ for paddy crops and 4.1 μmol $CO_2/m^2/s$ for wheat crops. The regression value (R^2) was in the range of 0.702 to 0.985, which shows that there was a strong impact of air pollutants on the photosynthetic rate of paddies and wheat crops (Table 6). The highest reduction in the photosynthetic rate compared to the control site was 46% and 48% at both the paddy and wheat crops, respectively, as shown in Table 7. The decrease in photosynthesis might be due to the deposition of dust on the leaf surface, which hampers the absorption of light and thereby causes a decline in the rate of photosynthesis (Mishra,1982). Similar to our findings, the ozone concentration of 40 ppb (85.6 μg/m^3) in controlled air chambers resulted in a reduction in the photosynthetic rate of paddy crops (Phothi and Theerakarunwong*,* 2017).

Stomatal conductance

The stomatal conductance (mmol $m^{-2}s^{-1}$) in the vegetative, reproductive and maturity stages of paddy and wheat crops at the nine sampling sites and control site is given in Table 5. In the vegetative stage, the minimum value of the photosynthetic rate for paddies was 0.11 mmol $m^{-2}s^{-1,}$ while the maximum value was 0.19 mmol $m^{-2}s^{-}1$ at the control site. In the reproductive stage of the wheat crop, the photosynthetic rate was reduced up to 0.14 mmol $m^{-2}s^{-}1$ in Mujedi compared to 0.26 mmol $m^{-2}s^{-}1$ in the control site. In the maturity stage, the minimum photosynthetic rate of paddy and wheat crops was 0.05 mmol $m^{-2}s^{-}1$ in Mujedi village, while the maximum photosynthetic rate was 0.08 mmol $m^{-2}s^{-}1$ for the paddy and wheat crop in control sites. Ram et al. (2014) reported that particulate matter damages the stomata in *Ficus benghalensis* and *Polyalthia longifolia* since the diameter of stomata was in the range of 8 to 12 μm. The regression value (R^2) is in the range of 0.704 to 0.837, which shows that there is a strong impact of air pollutants on the stomatal conductance of paddies and wheat crops (Table 6). The low stomatal conductance of leaves near gas-based power plants might be due to the high PM concentration, which hampers the opening of stomata and results in clogging of stomata. Similar studies have reported where air pollutants from the brick kiln industry have interrupted the stomatal functions of olive plants in Greece (Nanos *et al.,* 2007). The highest reduction in stomatal conductance compared to the control site was up to 48% in the paddy crop and 46% in the wheat cropping in both maturity stages, as shown in Table 7. Adrees *et al.* (2016) reported that wheat grown near brick kiln sites in Pakistan showed reduced stomatal conductance in wheat crops compared to low pollution sites and control sites due to injuries of stomata by PM_{10}, CO_2, NO_2 and SO_2. Zhang et al. (2020) reported that wheat grown in ozone fumigation stress caused a reduction in stomatal conductance in wheat crops by 19%. Ramya et al. (2021) conducted experiments on the exposure of wheat crops to elevated ozone (51 ppb or 100 μg/m3) in open top chambers, which resulted in a reduction of 21% stomatal conductance. Aziz et al. (2019) studied the effect of haze on rice crops and

Table 5. Photosynthetic rate (μmol $CO_2/m^2/s$), stomatal conductance (mmol $m^{-2}s^{-1}$), transpiration rate (μmol/m^2/s) of paddy and wheat

Sites	Paddy Vegetative	Wheat Vegetative	Paddy Reproductive	Wheat Reproductive	Paddy Maturity	Wheat Maturity
Photosynthetic rate (μmol $CO_2/m^2/s$)						
Mujedi	5.7	7.3	6	7.9	2.1	2.1
Faridpur	7.5	9.1	8	9.8	3.3	3.2
Sadupura	7.4	8.8	7.5	9.5	3	2.7
Bhuapur	6.8	8.2	7.3	8.9	2.8	2.3
Tigaon	5.8	7.7	6.1	8.2	2.2	2.8
Mandhawali	6	7.9	6.7	8.6	2.4	3
Gharora	7.9	9.5	8.9	10.1	3.6	3.5
Badraula	8.1	9.7	8.5	10.4	3.8	3.3
Khera	9.2	10.1	9.3	10.8	3.8	3.8
Ghazipur (control site)	9.5	12.8	10.2	13.9	3.9	4.1
Mean	7.39	9.11	7.85	9.81	3.09	3.08
Standard Deviation	1.34	1.59	1.39	1.72	0.69	0.63
Stomatal conductance (mmol $m^{-2}s^{-1)}$						
Mujedi	0.11	0.13	0.13	0.14	0.05	0.05
Faridpur	0.14	0.18	0.18	0.22	0.06	0.06
Sadupura	0.13	0.17	0.17	0.21	0.06	0.05
Bhuapur	0.12	0.16	0.17	0.18	0.05	0.05
Tigaon	0.11	0.13	0.14	0.16	0.05	0.06
Mandhawali	0.12	0.14	0.16	0.17	0.05	0.06
Gharora	0.14	0.18	0.19	0.22	0.07	0.07
Badraula	0.15	0.19	0.2	0.23	0.07	0.07
Khera	0.16	0.2	0.21	0.24	0.07	0.08
Ghazipur (control site)	0.19	0.24	0.25	0.26	0.08	0.08
Mean	0.14	0.17	0.18	0.20	0.06	0.06
Standard Deviation	0.02	0.03	0.03	0.04	0.01	0.01
Transpiration rate (μmol/m^2/s)						
Mujedi	5	6.5	5.2	6.8	1.3	1.7
Faridpur	5.5	7.3	6.1	7.6	1.5	2
Sadupura	5.4	7.2	5.8	7.4	1.5	1.8
Bhuapur	5.2	7	5.6	7.2	1.4	1.7
Tigaon	5	6.7	5.3	6.9	1.3	1.8
Mandhawali	5	6.8	5.4	7.1	1.4	1.9
Gharora	5.8	7.5	6.3	7.7	1.5	2.2
Badraula	5.9	7.9	6.4	8.1	1.6	2.1
Khera	6.8	8.1	7	8.6	1.6	2.4
Ghazipur (control site)	7.1	9.2	7.4	9.8	2	2.8
Mean	5.67	7.42	6.05	7.72	1.51	1.96
Standard Deviation	0.75	0.81	0.74	0.92	0.20	0.24

Table 6. Linear regression value R^2 of the air quality index (AQI) and physiological parameters: photosynthetic rate, stomatal conductance and transpiration rate

Crop	Phases	Photosynthetic Rate (R^2)	Stomatal conductance (R^2)	Transpiration Rate (R^2)	Yield (R^2)
Paddy	Vegetative	0.817	0.813	0.800	0.836
	Reproductive	0.718	0.704	0.856	
	Maturity	0.754	0.718	0.645	
Wheat	Vegetative	0.983	0.755	0.877	0.750
	Reproductive	0.985	0.785	0.875	
	Maturity	0.702	0.837	0.736	

Table 7. Reduction (%) in photosynthetic rate, stomatal conductance, transpiration rate and yield of paddy and wheat crops.

Crops	Paddy			Wheat		
Parameters	Vegetative	Reproductive	Maturity	Vegetative	Reproductive	Maturity
Photosynthetic Rate (%)	5-38	8-41	2-46	21-42	22-43	7-48
Stomatal conductance(%)	5-42	12-48	0-38	0-46	4-46	0-38
Transpiration Rate(%)	4-29	5-30	5-35	11-29	12-31	3-39
Yield(%)	-	-	0.4-11.6	-	-	0.8-14.8

found a reduction in stomatal conductance by 73.8% due to air pollution in Malaysia, where the air pollution index was moderate to polluted.

Transpiration rate

The transpiration rates (μmol/m^2/s) in the vegetative, reproductive and maturity stages of paddies and wheat at the nine sampling sites and control sites are given in Table 5. The minimum value of paddies was 1.3 μmol/m^2/s in the maturity stage in Mujedi, while the minimum value of wheat was 1.7 μmol/m^2/s in the maturity stage in Mujedi. Because of the interrupted gas exchange due to air pollutants, the stomatal conductance decreases, thereby lowering the rate of CO_2 assimilation and water absorption. This further slows the photosynthetic process as well as transpiration. The regression value (R^2) is in the range of 0.645 to 0.877, which shows that there is a strong impact of air pollutants on the transpiration rate of paddies and wheat (Table 6). The highest reduction in the transpiration rate compared to the control site was up to 35% in paddies and 39% in wheat, as shown in Table 7. This reduction in transpiration has a significant impact on the physiological water use efficiency of the plant. Stomatal conductance and transpiration rate are important functional parameters of any vegetation because they reveal a variety of environmental services that are linked to these physiological characteristics of plants (Singh *et al.,* 2017). Malav et al. (2017) reported similar results, where the transpiration rate of paddy crop reduced up to 44% was due to deposition of dust on leaves of paddy crops grown near thermal power plantin Dadri, Uttar Pradesh.

Yield attributes

The grain yields of paddy and wheat were in the range of 221.3–250.3 g/m^2 and 190.5- 223.6 g/m^2 respectively (Table 8). The yield reduction compared to the control site for paddies was up to 11.6%, and for wheat, it was up to 14.8%. (Table 7). Global O_3-induced wheat production losses were estimated to be between 5% and 26% in 2000, with additional losses of 1.5 to 10% predicted by 2030 (Avnery *et al.,* 2011; Van *et al.,* 2009). Mills *et al.* (2018) reported that ozone caused global yield losses of paddy and wheat by 4.4% and

Table 8. Yield of paddy and wheat crops at nine sampling sites and control sites

Sites	Rice yield (g/m^3)	Wheat Yield (g/m^3)
Mujedi	221.3	186.2
Faridpur	240.1	213.2
Sadupura	237.6	205.8
Bhuapur	232.4	196.7
Tigaon	224.6	188.3
Mandhawali	229.5	192.4
Gharora	242.3	219.6
Badraula	246.8	224.3
Khera	249.3	231.8
Ghazipur (control)	250.3	241.2

7.15%, respectively, in India and China, which is similar to our findings in Faridpur and Sadupura, where the reductions in paddy and wheat were 4% and 7.9%, respectively. Pleijel et al. (2018) studied the effect of ozone with charcoal filtration and nonfiltration on wheat crops and found that there was an up to 8.4% reduction in the grain yield of wheat in nonfiltration compared to charcoal filtration. Broberg *et al.* (2015) conducted 42 experiments on the effects of ozone on wheat grain yield in Asia, Europe and North America and found that ozone reduces the yield of wheat crops. Mukherjee *et al.* (2021) found that under ambient O_3 concentrations, the sequence of sensitivity in main crops is wheat > mustard > rice > maize.

Conclusion

The results showed that the air pollutants in Faridabad due to different sources in Faridabad affected the paddy and wheat crops grown near the study area. The regressor value R^2 calculated in our study showed that there was a significant impact of air pollution on physiological parameters such as photosynthetic rate, transpiration rate and stomatal conductance and yield attributes of paddies and wheat crops. The crops grown at the control site had higher values of photosynthetic rate, stomatal conductance and transpiration rate of paddy and wheat crops compared to polluted sites. These findings offer an intriguing paradigm for leaf responses to environmental differences, demonstrating that the ability of leaves to regulate photosynthesis and transpiration leads to significant changes in water use efficiency. Air pollution also caused reductions in the yields of paddies and wheat by 11.6% and 14.8%, respectively. There is a need to study the effect of air pollution on different crops (maize, soybean, bajra, etc.) Therefore, crops that are resistant to air pollution can be grown in polluting sites, and crops that are sensitive to air pollution can be grown where the air quality index is good, which will result in better crop production.

Conflict of interest

The authors declare that they have no conflicts of interest.

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