Susceptibility of Some Wheat (*Triticum aestivum* L.) Varieties to Aerosols of Oxidised and Reduced Nitrogen

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**Abstract**

In a pot culture (2011), aerosols of oxidized nitrogen (NaNO3) @20 kg ha–1 yr–1 (≈200 ppm), reduced nitrogen (NH4Cl) @10 kg ha–1 yr–1 (≈100 ppm) and distilled water (control) were sprayed (1500 cm2 plant–1 of each solution) weekly at different days after sowing (DAS) to study their impacts on physiology of wheat varieties (Ankur Omkar, Sonalika and K-306). In a field trial (2012), the simulated N-aerosols @ 200 ppm and 400 ppm (1000 cm3 m2 for each solution) along with a control were sprayed to population of the best variety (Ankur Omkar) at four different growth stages. In both pot and field experiments foliar feeding of aerosols with lower dose at the earlier growth stages influenced nitrogen use efficiency and yield. Fluctuations of cellular cations (Ca2+, K+) or peroxidase activity were caused by the aerosols and altered membrane permeability.

**Keywords**: Cations; Nitrogen use efficiency; Nitrate reductase; Net photosynthesis; Peroxidase; Membrane permeability

**Abbreviations**: NaNO3: Sodium Nitrite; NH4Cl: Ammonium Chloride; NUE: Nitrogen Use Efficiency; NR: Nitrite Reductase; CMS: Cell Membrane Stability; DAS: Days after sowing; CRI: Crown Root Initiation; Pn: Net Photosynthesis; d.w: Dry Weight

**Introduction**

Nitrogen oxides (NO, NO2 and N2O or NO3–) are recognized as atmospheric pollutants in rapidly growing urban and peri-urban areas of Northeast India [1]. Nitrogen dioxide gets dissolved in the extra-cellular water, form HNO2 and HNO3, which then dissociate to extra-cellular water, form HNO2 and HNO3, which then dissociate to acidification of the ecosystem [5,6]. NH4 contributes to a wide range of compounds in nearly all higher plants [3]. Higher concentration (<10 µM) of oxides of nitrogen alter the physiological processes including net photosynthesis and yields [4].

Reduced nitrogen (gaseous NH3 or particulate NH4+ called NH4+) causes acidification of the ecosystem [5,6]. NH4 contributes to a substantial portion of total deposition of nitrogen [7]. Ammonia at high concentration (>1 mM) is toxic to plants [8]. The consequences of high N deposition are seen in terrestrial ecosystem [9]. Foliar feeding of plants with aerosols of oxidised (NaNO3) and reduced nitrogen (NH4Cl) might affect growth stages and yield attributes of wheat varieties. We examined dose responses of wheat crop to N-aerosols and discussed mechanism(s) for varietal susceptibility or tolerance to the aerosols.

**Materials and Methods**

**Cultural practices**

Three wheat cultivars viz., K-306, Sonalika and Ankur Omkar were included in the pot experiments. A mixture (5 g) of urea, super phosphate and muriate of potash @2:1:1 were added to acid mineral soil in pots (size 5 kg) before raising plants from the seeds. In field, these fertilizers at 80:46:42 per hectare were applied as basal before sowing of wheat seeds (variety: Ankur Omkar). The crop was irrigated during the growth periods to avoid desiccation. The experiments were laid in Randomized Block Design and replicated thrice.

**Application of aerosols**

In pot experiment 100 ppm NH4Cl and 200 ppm NaNO3 were sprayed on foliage at four growth stages viz., 0-30 DAS: germination cum crown root initiation (CRI); 30-60 DAS: tillering; 60-90 DAS: maximum tillering; and 90-120 DAS: reproductive development. Total volume of the each solution was 1500 cm3 per stage. Similarly, solutions (1000 cm3 per stage) each of 200 ppm NH4Cl and 200 ppm NaNO3 and distilled water (control) were sprayed to population of wheat crop at the four different growth stages. Drifting of the solutions from one pot to plot to another was prevented by using a hard board at the time of spray.

**Measurement of net photosynthesis**

We used transparent, airtight acrylic assimilation chambers (60 x 60 x 60 cm3 for pot plants and 15 x 15 x 15 cm3 field samples). Temperature (27–29°C), Relative humidity (52–57%) and Light intensity (23–27 Klux) inside the assimilation chambers were recorded by Hygrometer and Light meter respectively. The pot plants or leaf samples from field were incubated in presence of ambient 380 ppm CO2 in sunlight during mid-day for half an hour. Inside air sample (10 cm3) was collected by clinical syringe through the rubber port of the chambers, and injected into Environmental Gas Monitor (EGM-4) for measuring carbon dioxide concentration after incubation of plants inside the assimilation chamber. The rate of net photosynthesis was expressed as ppm CO2 absorbed g–1 plant Dhw–1 [10].

**NR activity in plants**

Nitrate reductase activity was estimated based on conversion of nitrate to nitrite and inhibition of nitrate reduction to ammonia in anaerobic condition [11]. Green leaf samples (0.03 g) of 10-15 mm2 size were put into 2.5 ml solution containing 200 mM phosphate buffer (pH 7.5). At 37°C, the reaction mixture was placed into a water bath for 10 min. The reaction was stopped by putting the mixture in ice-cold water. After centrifugation, the absorbance was measured at 540 nm in a spectrophotometer for determination of nitrite content.

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buffer (pH 7.5), 30 mM KNO₃, 5% (v/v) propanol in assay tubes. The tubes were incubated in a water bath at 30°C for 30 minutes, at 100°C for 2 minutes and allowed them to cool to room temperature. To detect nitrite, 1 ml each of 1% sulfanilamide in 1N HCl and 0.02% N-(1-naphthyl)-ethylene diamine dihydrochloride were added to the solution. The solution was mixed thoroughly and kept in dark at room temperature for 15 min. Then, absorbency readings measured at 540 nm by spectrophotometer were plotted on a standard curve, which was prepared from a stock of 25 nmol nitrite per ml using KNO₃ in water.

**Peroxidase activity in plants**

Lipid peroxidation was measured in terms of Malondialdehyde content (MDA) [12]. Leaf sample (0.5 g) was homogenized in 10 ml of 0.1 per cent trichloroacetic acid. The homogenate was centrifuged at 15,000 g for 5 minutes. The aliquot (2 ml) of the supernatant and 4 ml of 0.5% thiobarbituric acid (TBA) in 20 per cent of TCA were mixed. The mixture was heated at 95°C for 30 minutes and cooled in ice bath. It was centrifuged at 10,000 g for 5 minutes and the absorbance of supernatant was recorded at 532 nm. The value for non-specific absorption at 600 nm was subtracted from the value of 532 nm. The absorption coefficient of 155 nmol per cm was used to calculate MDA content.[12]

**Nitrogen use efficiency (NUE) of crop**

Kjeldhal method was used to determine total Nitrogen content, which is based on catalytic conversion of organic nitrogen into ammonia and its subsequent estimation by acid base titration [13]. NUE in grains of wheat varieties under treatments were calculated from their per cent Nitrogen and dry weight as: NUE% in grain = (Nitrogen % in grain x total grain yield per plant or per plot).

**Measurement of CMS and estimation of cations**

Cell Membrane permeability was measured in terms of CMS [14]. Twenty pieces of young leaves from the treated plants were cut into size of one centimetre square and immersed them first into 20 cm³ distilled water in plastic bottles of 60 cm³ capacity. The bottles were closed tightly to avoid leaking of the solution and checked gently using magnetic stirrer. Thus, freely water soluble ions in intercellular spaces of leaf were removed by the three serial washes with distilled water (each 10 min, 20 cm³). Then, to extract the cations present in the exchangeable sites of the cellular locations, the same leaf discs were eluted by two treatments (each 1 h 20 cm³) with 25 mM Sr₂Cl₂ [15]. The solutions were collected into other plastic bottles. The plant samples were oven dried at 60°C to a constant weigh. The electrical conductivity readings of these solutions against the samples collected from the experimental treatments were used to compute CMS as follows.

\[
CMS = \frac{1}{(1-\frac{T}{T1/T2})/(1-C1/C2)} \times 100
\]

Where, 
- \(T\) = Conductivity reading of 25 mM Sr₂Cl₂ (20 cm³) without leaf samples
- \(T1\) = Conductivity readings of 25 mM Sr₂Cl₂ (20 cm³) with leaf samples
- \(C\) = Conductivity reading of double distilled water without leaf samples
- \(C1\) = Conductivity readings of double distilled water with leaf samples

Intercellular and exchangeable Cations (K⁺ and Ca²⁺) extracted by distilled water and 25 mM Sr₂Cl₂ respectively, were estimated using a Thermo Jarrel Ash S12 atomic absorption/emission spectrophotometer (Franklin, MA, USA) and air-acetylene mixture. Element contents of the leaves were expressed in terms of their oven dry weight.

**Economic yield**

Grains were threshed out from the plants under respective treatments at different growth stages of wheat crop and expressed as gram per plant (in case of pot plants) and quintal per hectare in field harvest.

**Statistical analysis**

Data were analysed following Generalised Linear Model (GLIM) program of Royal Society of London. Significant differences between two mean values due to treatments or varieties and their interaction at a crop growth stage were computed by comparing their significant levels at P<0.05.

**Results**

**Net photosynthesis**

In the pot experiment (Table 1), Pn at the germination-cum CRI stage of the crop (i.e.0-30DAS) varied significantly among the varieties. The variety Ankur Omkar had the highest Pn followed by Sonalika>K-306. In general, NH₄Cl lessened and NaNO₂ increased Pn by about 1% and 7.89% respectively. The Pn differed significantly due to treatments at tillering stage (i.e. 30-60 DAS) of the crop. There were 16.71% and 29.52% reductions of Pn NH₄Cl and NaNO₂ respectively. Variety Ankur Omkar had the highest Pn followed by K-306>Sonalika. Both varieties and treatments had significant effects on Pn at the maximum tillering stage i.e. 60-90 DAS. Variety K-306 showed the highest Pn.

<table>
<thead>
<tr>
<th>Varieties - Treatment ↓</th>
<th>Stage I (0-30DAS)</th>
<th>Stage II (30-60 days after sowing : DAS)</th>
<th>Stage III (60-90 DAS)</th>
<th>Stage IV (90-120DAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varieties</td>
<td>Control</td>
<td>NH₄Cl (100 ppm)</td>
<td>NaNO₂ (200 ppm)</td>
<td>Control</td>
</tr>
<tr>
<td>K-306</td>
<td>117.1</td>
<td>151.7</td>
<td>133.2</td>
<td>1064.9</td>
</tr>
<tr>
<td>Sonalika</td>
<td>140.2</td>
<td>124.1</td>
<td>158.2</td>
<td>807.9</td>
</tr>
<tr>
<td>Ankur Omkar</td>
<td>160.7</td>
<td>138.8</td>
<td>159.4</td>
<td>786.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Varieties - Treatments</th>
<th>Stage I (0-30DAS)</th>
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<th>Stage IV (90-120DAS)</th>
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<table>
<thead>
<tr>
<th>Varieties</th>
<th>Treatment</th>
<th>LSD (0.05)</th>
<th>SEdiff (±) LSD (0.05)</th>
<th>SEdiff. (±) LSD (0.05)</th>
<th>SEdiff (±) LSD (0.05)</th>
<th>SEdiff (±) LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>-</td>
<td>n.s.</td>
<td>91.72</td>
<td>164.17</td>
<td>151.98</td>
<td>331.18</td>
</tr>
<tr>
<td>Treatment</td>
<td>32.792</td>
<td>72.176</td>
<td>6518.7</td>
<td>14347</td>
<td>-</td>
<td>n.s.</td>
</tr>
<tr>
<td>Variety x Treatment</td>
<td>-</td>
<td>n.s.</td>
<td>0.358</td>
<td>0.810</td>
<td>-</td>
<td>n.s.</td>
</tr>
</tbody>
</table>
followed by Sonalika > Ankur Omkar at this stage. NH₄Cl and NaNO₂ brought down Pₚ by 9.89% and 15.704% respectively as compared to the control. The varieties had significant differences in respect of Pₚ at the reproductive development stage i.e. 90-120 DAS of the crop only. The order of Pₚ in varieties was K-306 > Ankur Omkar > Sonalika.

In the field experiment (Figure 1), the treatments brought about significant changes in Pₚ of the wheat crop. Plants treated with the oxidised and reduced nitrogen had lower Pₚ by 5-6.5% only as compared to control. However, there were higher variations in Pₚ with respect to crop stages. The Pₚ declined at the later growth stages with application of the aerosols (Stage 1 (20.58%) > Stage 2 (46.82%) > Stage 3 (15.33%) > Stage 4). It may be due to the negative impact of the aerosols at the later growth stages as compared to the earlier ones.

Nitrate reductase activity activity

In the pot experiment (Table 2), both varieties and treatments had significant effects on NR activity of wheat crop. The effects of NH₄Cl on NR of varieties were negligible, whereas NaNO₂ increased NR activity merely (by 6.48%) as compared to control. Variety Ankur Omkar possessed the highest NR followed by Sonalika > K-306. At the maximum tillering stage, NR activity was significantly affected by variety and treatments. Variety Ankur Omkar had the highest NR followed by Sonalika > K-306. NH₄Cl enhanced NR activity by 34.07% and NaNO₂ by 7.69% as compared to control. Neither the variety nor the treatments at reproductive development stage exhibited significant changes in NR activity.

In the field experiment (Figure 2), NR activity varied significantly due to the treatments with respect to time of application. Leaves treated with aerosols had lower NR activity. There were decreases in NR activity by NaNO₂ (21.62% and 28.0%) than by NH₄Cl (19.39%, 11.26%) at 200 and 400 ppm respectively. Also, lower NR activity was found with the higher doses of the aerosols.

Nitrogen use efficiency

Data on NUE in wheat grains from the pot experiment are presented in Table 3. In this experiment, there were 1.87% and 8.88% reductions of grain NUE in NH₄Cl and NaNO₂ treated plants respectively. Some differences in NUE were found among the varieties, where Sonalika > Ankur Omkar > K-306. The variety and treatments had significant effects on grain NUE at maximum tillering stage of the crop.
There were 16.1% and 19.1% increases in grain NUE by NH₄Cl and NaNO₂ respectively. Variety Ankur Omkar ranked first followed by stage 1 (18.84%) > stage 4 (17.27%) > stage 3 (9.68%) > stage 2 (5.00%). There were reductions in yield with application of aerosols at later stage (Stage 1 > Stage 2 > Stage 4 > Stage 3). There were 21.74% and 27.03% increases in grain NUE by NH₄Cl and NaNO₂ respectively). NUE fluctuates at different days after sowing (Stage 2 (18.84%) > Stage 4 (17.27%) > Stage 3 (9.68%) > Stage 1). Economic yield

In the pot experiment (Table 4), CMS was affected significantly by the treatments at tillering stage of wheat crop. Variety Ankur Omkar > K-306 > Sonalika had differences in CMS. Both varieties and treatments had significant effects on CMS of wheat crop at maximum tillering stage. K-306 > Ankur Omkar > Sonalika had a variable CMS. There were reductions in yield with application of aerosols at later stage (Stage 1 > Stage 2 > Stage 4 > Stage 3). There were 21.74% and 27.03% increases in grain NUE by NH₄Cl and NaNO₂ respectively. The variety Ankur Omkar had higher grain NUE than K306 > Sonalika varieties.

In the field experiment, NUE (Figure 3) increased in leaf at 400 ppm NH₄Cl as well as 200 ppm and 400 ppm NaNO₂ treatments (by 25.47%, 26.17% and 4.38% respectively). NUE fluctuates at different days after sowing (Stage 2 (18.84%) > Stage 4 (17.27%) > Stage 3 (9.68%) > Stage 1). Cell membrane stability

In the pot experiment (Table 4), CMS was affected significantly by the treatments at tillering stage of wheat crop. Variety Ankur Omkar > K-306 > Sonalika had differences in CMS. Both varieties and treatments had significant effects on CMS of wheat crop at maximum tillering stage. K-306 > Ankur Omkar > Sonalika had a variable CMS. On an average, N-aerosols applied at the reproductive development stage, had significant effects on CMS of Wheat crop. Ammonium chloride and Sodium nitrite increased CMS up to 46.62% and 84.46% respectively as compared to control. The varieties Sonalika > Ankur Omkar > K-306 had some differences in their CMS.

In the field experiment (Figure 4), Cell membrane stability of wheat did not differ significantly for the treatments. However, a higher CMS was found in early application of the aerosols than at the later stage (Stage 1 > Stage 2 > Stage 3 by 1.22%, 13.63%, 5.36% respectively).

Economic yield

In the pot experiment, economic yield of wheat varieties corresponding to the treatments are presented in Table 5. N-aerosol applied at tillering stage of the crop had significant effects on grain yield. NH₄Cl decreased (by 14.95%) and Sodium nitrite increased (by 21.74%) of grain yield. The varieties K-306 > Ankur Omkar > Sonalika had variations in their grain yield. The treatments at the maximum tillering stage had significant effects on economic yield. NH₄Cl and NaNO₂ increased grain yield by 22.9% and 42.81% respectively at this stage. Varieties Ankur > K-306 > Sonalika differed from each other in grain yield production. The application of N-aerosols at the reproductive development stage couldn’t change grain yield significantly.

In field experiment, the treatments had significant effects on economic yield of wheat crop (Figure 5). In general, NH₄Cl could not change but NaNO₂ decreased economic yield by 15.03% and 25.81% at 200 ppm and 400 ppm respectively. Lower was the concentration of the oxidised aerosol, higher was the production of yield of the crop. There were reductions in yield with application of aerosols at later stage (Stage 1 > Stage 2 > Stage 3).

### Table 3: Variation in Nitrogen use efficiency (NUE) in grain of wheat varieties following treatment at different growth stages (Days after sowing: DAS) in laboratory conditions.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Treatment</th>
<th>NUE % in grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>N1: Distilled water, N2: 400 ppm NH₄Cl, N4: 200 ppm NaNO₂</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Table 4: Cell membrane stability (CMS) of wheat varieties following treatment at different growth stages (Days after sowing: DAS) in laboratory conditions.

<table>
<thead>
<tr>
<th>Stages after sowing (DAS)</th>
<th>Stage II (30-60 DAS)</th>
<th>Stage III (60-90 DAS)</th>
<th>Stage IV (90-120 DAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety x Treatment</td>
<td>SEdiff</td>
<td>LSD (0.05)</td>
<td>SEdiff</td>
</tr>
<tr>
<td>Control</td>
<td>-1.34</td>
<td>-0.82</td>
<td>0.89</td>
</tr>
<tr>
<td>NH₄Cl (100 ppm)</td>
<td>6.32</td>
<td>3.60</td>
<td>4.56</td>
</tr>
<tr>
<td>NaNO₂ (200 ppm)</td>
<td>5.48</td>
<td>3.09</td>
<td>5.64</td>
</tr>
</tbody>
</table>

SE diff: Standard error of difference between two treatment means, varieties or their interaction; LSD: Least significant difference; n.s: Non significant at P (0.05).
Peroxidase activity

The PO activity (Figure 6) in leaf of wheat (variety: Ankar Omkar) was determined in the field trial only. There were significant effects of the nitorgenous aerosols on PO at different DAS. The leaves treated with aerosol of oxidised nitrogen had higher PO (by 16.56% and 13.57%) than the reduced nitrogen (2.259% and -1.83%) at 200 and 400 ppm respectively. The PO also increased commensuration with crop growth stages (Stage 1 (37.03%) < Stage 2 (4.82%) < Stage 3 (65.74%) < S4).

Distribution of cations

Cations (Ca²⁺ and K⁺) present in intercellular and exchangeable sites varied significantly among the wheat varieties due to the aerosol treatments (Table 6). NH₄Cl depleted more cations from the water free spaces and exchangeable sites than the oxidized nitrogen.

Discussion

The present investigation into the impacts of oxidized and reduced nitrogen aerosols (viz., NaNO₂ and NH₄Cl respectively), applied at different growth stages of Wheat (Triticum aestivum L.) crop, deals with physiological parameters contributing to higher grain yield production. We also attempted to sort out the most suitable variety and its stage responding positively to the aerosol of nitrogen. The mechanism(s) of injury to the varieties by the nitrogenous compounds are discussed in this paper [16].

In pot culture experiment, the simulated aerosols were NH₄Cl @100 ppm (≅ 10 kgNHa⁻¹ yr⁻¹) and NaNO₂ @ 200 ppm (≅ 20 kgNHa⁻¹ yr⁻¹) respectively. These were applied at different growth stages of wheat crop. We preferred the N-aerosols as foliar feeding to fumigating plants. The rate of Pn in wheat varieties varied significantly following foliar feeding. The Pn rate in crop varieties also different due to the differences in nitrogen input from the aerosols at their growth stages. There are several previous reports on Pn depression in higher plants by nitrogenous pollutants. A concentration at 0.6 µll⁻¹ may cause Pn inhibition of oat (Avena sativa L) and alfalfa (Medicago sativa L) during 90 min fumigation [17]. Similarly there is evidence that decrease in Pn of bean (Phaseolus vulgaris) is related to 1-7 µll⁻¹ NO₂ over a period of 5 h [18]. Chloroplastic pH increases when the number of protons in the chloroplast exceeds the proton required (six) for a NO₂ reduction. The key enzyme of carbon assimilation (ribulose-1,5-bisphosphate carboxylase/oxygenase) is pH dependent. Such changes in pH are likely to be harmful [19]. Photosynthetic depression has also been related to ultra structural changes in plants by NO₂. The changes and its stage responding positively to the aerosol of nitrogen. The production. We also attempted to sort out the most suitable variety and its stage responding positively to the aerosol of nitrogen. The mechanism(s) of injury to the varieties by the nitrogenous compounds are discussed in this paper [16].

There are several previous reports on Pn depression in higher plants and its stage responding positively to the aerosol of nitrogen. The production. We also attempted to sort out the most suitable variety and its stage responding positively to the aerosol of nitrogen. The mechanism(s) of injury to the varieties by the nitrogenous compounds are discussed in this paper [16].
Table 6: Effects of oxidised (NaNO₂) reduced (NH₄Cl) nitrogen aerosols on distribution of Calcium and Potassium ions in intercellular and exchangeable sites of Wheat (Triticum aestivum L.) crop treated at different days after sowing (DAS) under laboratory conditions.

<table>
<thead>
<tr>
<th>Varieties (V:1,2,3)</th>
<th>K-306 (mM g⁻¹d.w.)</th>
<th>Sonalika (mM g⁻¹d.w.)</th>
<th>Ankur Omkar (mM g⁻¹d.w.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments (T:1,2,3)→</td>
<td>DistilledH₂O (0ppm)</td>
<td>NH₄Cl (100 ppm)</td>
<td>NaNO₂ (200 ppm)</td>
</tr>
<tr>
<td>30-60 DAS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercellular Ca²⁺</td>
<td>19.86</td>
<td>26.80</td>
<td>29.11</td>
</tr>
<tr>
<td>Exchangeable Ca²⁺</td>
<td>55.71</td>
<td>27.29</td>
<td>65.70</td>
</tr>
<tr>
<td>Intercellular K⁺</td>
<td>1.12</td>
<td>1.10</td>
<td>1.64</td>
</tr>
<tr>
<td>Exchangeable K⁺</td>
<td>2.88</td>
<td>1.70</td>
<td>3.28</td>
</tr>
<tr>
<td>60-90 DAS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercellular Ca²⁺</td>
<td>18.33</td>
<td>12.92</td>
<td>19.97</td>
</tr>
<tr>
<td>Exchangeable Ca²⁺</td>
<td>24.47</td>
<td>23.60</td>
<td>26.85</td>
</tr>
<tr>
<td>Intercellular K⁺</td>
<td>1.39</td>
<td>1.11</td>
<td>1.53</td>
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<tr>
<td>Exchangeable K⁺</td>
<td>2.42</td>
<td>2.86</td>
<td>1.91</td>
</tr>
<tr>
<td>90-120 DAS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercellular Ca²⁺</td>
<td>4.43</td>
<td>88.87</td>
<td>59.78</td>
</tr>
<tr>
<td>Exchangeable Ca²⁺</td>
<td>16.45</td>
<td>114.02</td>
<td>215.71</td>
</tr>
<tr>
<td>Intercellular K⁺</td>
<td>0.32</td>
<td>2.65</td>
<td>4.09</td>
</tr>
<tr>
<td>Exchangeable K⁺</td>
<td>0.77</td>
<td>6.19</td>
<td>9.92</td>
</tr>
</tbody>
</table>

P (0.05): Significant at 5% probability level.

Potted plants were subjected to three different treatments, viz., distilled water (control), NaNO₂ (100 ppm) and NH₄Cl (100 ppm). The DistilledH₂O (200 ppm) and NaNO₂ (200 ppm) treatments were applied at 30-60 DAS, 60-90 DAS, and 90-120 DAS, respectively, in a randomized complete block design with three replications. The experiment was conducted in an air-conditioned laboratory to ensure a constant temperature of 25°C and a relative humidity of 60%. The plants were grown in 1-L pots filled with a mixture of sand and soil (1:1) and were watered daily to maintain optimal growth conditions.

The NR Nitrate activity in wheat was lowered in shoots by NH₄Cl at P(0.05) T<T₂ only. As NH₄Cl treated plants had higher leakage of ions from the cells, therefore, the membrane damages caused by NH₄Cl and NaNO₂ at almost all stages of the crop. The varieties differed in the response to N for physiological stability [31]. Calcium ions binds with modulator proteins e.g. calmodulin [32], and serves as chemical signaling that in some cases

neglected as non-physiological at relatively alkaline pH (>5.0) of the aerosols in our work.

In the present study, NUE in wheat increased with treatments of N-aerosols at their growth stages except a few. On an average, varieties also showed remarkable differences in their NUE in grains. However, NUE in grains decreased with the higher concentration of nitrogen aerosols in both pot culture and in field experiments. The differences between accessions in the response to N for physiological and phonological variables exist in case of Arabidopsis lyrata petrae [25]. Moreover we found that nitrogen nutrition enhanced grain yield of wheat varieties irrespective of their growth stages. The enhancement is more prominent in NaNO₂ than NH₄Cl fed plants. Higher nitrogen use efficiency with lower quantity of nitrogen from the source might improve nutritive quality of the crop varieties [26] but it showed a negative impact on productivity of cereal crops. The wheat varieties having higher grain yield were found with treatments at maximum tiller formation stage (60-90 DAS). In wheat, Ankur Omkar followed by K-306 and Sonalika emerged as commendable varieties. In these potential varieties, cell membrane stability was found to be higher irrespective of treatments. Cell membrane permeability was increased (with lower CMS) by both NH₄Cl and NaNO₂ as compared to control. As NH₄Cl treated plants had higher leakage of ions from the cells, they possessed higher quantum of the cations in the intercellular and exchangeable sites. Similarly, NaNO₂ treated plants had higher CMS and lower membrane leakage than NH₄Cl treated plants, a lower amount of the cations were recovered from the cellular locations. The rate of PO activity of wheat crop treated with NaNO₂ was higher than the rate shown by the NH₄Cl treatment as compared to the control. Therefore, the membrane damages caused by NH₄Cl and NaNO₂ were brought by two different mechanisms. The former depleted the cations from the membrane directly and the later caused peroxidation of lipids present in the membrane. Hence, the membrane became leaky for the cations, and their quantum was higher in the intercellular and exchangeable sites irrespective of varieties, which were detected in the extraction processes with water and SrCl₂ solutions respectively. Although, nitrite causes swelling of thylakoids and changes membrane stability, direct interference of free radicals with critical enzymes [27] may be responsible for reduction in growth and yield of crops. The oxides of nitrogen following the lipid breakdown in membrane cause cellular plasmolysis [28]. Apart from uncoupling electron transport chain in chloroplast [29], ammonia reduces cations viz., Calcium, magnesium, and potassium [30]. In plant cells, calcium is one of the integral components of plasma membrane, where it helps maintain stability [31]. Calcium ions binds with modulator proteins e.g. calmodulin [32], and serves as chemical signaling that in some cases
might have some roles on physiological variations and productivity of the crop stage-wise. There are differences between species imparting carbon dioxide fixation, and reduction of nitrite only at low light levels and high nitrite concentration [34]. So, the effects of irradiance, temperature and even desiccation on the pollution responses of the selected crop varieties and role of oxidative damage in these responses are important thrusts. All these largely indicate that the changes of the physiological parameters and productivity of the winter wheat crop may have quite different facets in context with the impacts of nitrogenous pollutants.

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References


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