Crop Response to Abiotic Stresses of Effluent, Salinity and Heavy Metal I – Comparative Percentage Seed Germination in Mustard and Wheat

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Abstract

The results in relation to the effect of different concentrations of the three types of environmental (abiotic) stresses viz., Stress I (Effluent); Stress II (Salinity); Stress III (Heavy metal) under varying concentration levels (0, 25, 50, 75 & 100 % (Stress I); 0, 4, 8, 12 & 16 EC dsm⁻¹ (Stress II) and 0, 100, 200 & 300 ppm (Stress III) with distilled water as control on germination performance measured in terms of percent germination after 24, 48, 72, 96 and 120 hours of sowing. For these studies two important crops of the region, one legume crop (Mustard - Brassica campestris L; family Brassicaceae) and another cereal crop (Wheat - Triticum aestivum L; family Poaceae/Gramineae), were taken for screening. Interestingly it has been observed that with increasing stress seed germination is delayed as well as reduced. There was also a differential response in percentage germination and tolerance to different types of stresses with respect to crops grown. Results have shown that the highest average germination percentage (GP) of 95.233% was observed in the crop Wheat in 50% of Stress I at 120 hours while lowest GP of 1.000% was also observed in the crop Wheat in 300 ppm of Stress III at 72 hours. Besides, both the crops Mustard and Wheat did not show any seed germination at all in 100% (Stress I), 16 dsm⁻¹ (Stress II) and 300 ppm (Stress III) concentrations at 24 hours and in 300 ppm (Stress III) at 48 hours also. Further, it was observed that 75% (Stress I), 12 dsm⁻¹ (Stress II) and 200 ppm (Stress III) concentrations for three types of stresses and also 72 hours of germination were found to be quite critical for the two crops, therefore, on the basis of percent over control at 72 hours with 75% (Stress I), 12 dsm⁻¹ (Stress II) and 200 ppm (Stress III) concentrations respectively the germination percentage in the two crops showed a trend as percent change over control: Stress I (Effluent) – Mustard [45.150% (-28.021)], Wheat [38.450% (-43.412)]; Stress II (Salinity) – Mustard [38.483% (-38.650)], Wheat [35.450% (-47.827)] and Stress III (Heavy Metal) – Mustard [14.817% (-76.379)], Wheat [10.783% (-84.130)] showing better performance of the leguminous crop than the cereal crop.

Keywords: Seed germination; Effluent; Salt; Heavy metal; Stress; Legume crop; Cereal crop

Introduction

An increasingly greater concern for water quality problem has been shown for the past few decades due to steep rise in population in cities and urban areas. Unprecedented and rapid industrial development, un-thoughtful use of natural resources and building of huge urban complexes are responsible for changing the natural pattern creating several environmental pollution problems causing water quality deterioration. Though development in the modern sense as a whole is blamed for most of the water quality problems but urbanization has been the major cause and the centre of the problem. In India water quality of fresh waters both surface and ground water has been a subject of much investigation, however, most of these studies assume the ecosystem as a separate entity and attempts have rarely been made to study the problem in larger aspects as studying drinking and irrigational problems with reference to the water demand, pollution load, degree of treatment, ecological process including effects on animals, human being and vegetation especially our crop plant Sharma [1], Parashar [2], Pathak [3], Saraswat [4], Snehlata [5], Parashar et al. [2] as studied in the present investigation. Environmental Problems in Mathura with special reference to Yamuna River water problems were studied by Sharma [6], Sharma [1], Parashar [7] The present study is an effort an aims at detailed study of potential water quality problems in the light of industrial and urban development in Mathura, UP (India) with an attempt to see its impact on plant growth and development, vis-à-vis on animal and human
population, especially agricultural crops of the region so that the quality of city and industrial effluent water of Yamuna River is best utilized for irrigation to raise higher crop yield.

**Experimental Materials and Methods**

We know a continuous deficit of good-quality fresh water implies that agriculture must use alternative resources such as saline water and sewage and industrial effluents for increasing agricultural production for ever-growing population besides abating pollution of our major river systems and other water-bodies as such to evaluate the effects of water quality as city and industrial effluent and soils irrigated, seed lots of certain crops were screened for their relative tolerance to three types of environmental abiotic stresses viz., Stress I (City and industrial effluents); Stress II (Saline water as sodium chloride NaCl) and Stress III (Heavy metal mercury as HgCl$_2$) under varying concentration levels viz., 0, 25, 50, 75 & 100 % (for city & industrial effluents); 0, 4, 8, 12 & 16 EC ds m$^{-1}$ (for NaCl) and 0, 100, 200 & 300 ppm (for HgCl$_2$). Distilled water was used as control in all the three types of environmental stress treatments.

**Table 1:** Mean, Standard Error, CV And Cd Table Physico-Chemical Analysis of City And Industrial Effluents At Mathura

| Effluent Physico-Chemical Parameters | Values          |
|--------------------------------------|-----------------|
| 1. Colour                            | Yellowish       |
| 2. Odour                             | Stinking-pungent|
| 3. Transparency                      | Yellowish       |
| CD = 0.128                           | CV = 1.006      |
| 5. Temperature (°C)                  |                 |
| Mean ± SEM                           | 33.00 ± 1.732   |
| CD = 0.128                           | CV = 6.761      |
| 6. pH                                |                 |
| Mean ± SEM                           | 8.30 ± 0.115    |
| CD = 0.128                           | CV = 5.249      |
| 7. Conductivity (mg/l)               |                 |
| Mean ± SEM                           | 93.00 ± 0.333   |
| CD = 0.128                           | CV = 2.098      |
| 8. Total alkalinity (mg/l)           |                 |
| Mean ± SEM                           | 315.33 ± 2.728  |
| CD = 0.128                           | CV = 1.350      |
| 9. Free CO2 (mg/l)                   |                 |
| Mean ± SEM                           | 233.67 ± 2.028  |
| CD = 0.128                           | CV = 1.572      |
| 10. DO (mg/l)                        |                 |
| Mean ± SEM                           | 81.33 ± 0.882   |
| CD = 0.128                           | CV = 3.193      |
| 11. BOD (mg/l)                       |                 |
| Mean ± SEM                           | 211.33 ± 1.856  |
| CD = 0.128                           | CV = 1.903      |
| 12. COD (mg/l)                       |                 |
| Mean ± SEM                           | 416.33 ± 0.667  |
| CD = 0.128                           | CV = 1.074      |
| 13. TSS (mg/l)                       |                 |
| Mean ± SEM                           | 1212.00 ± 2.082 |
| CD = 0.128                           | CV = 0.598      |
| 14. TDS (mg/l)                       |                 |
| Mean ± SEM                           | 1971.33 ± 2.404 |
| CD = 0.128                           | CV = 0.422      |
| 15. Cl$^-$ (mg/l)                    |                 |
| Mean ± SEM                           | 676.67 ± 1.856  |
| CD = 0.128                           | CV = 0.781      |
| 16. Ca$^2+$ (mg/l)                   |                 |
| Mean ± SEM                           | 286.67 ± 4.096  |
| CD = 0.128                           | CV = 1.752      |
| 17. Na$^+$ (mg/l)                    |                 |
| Mean ± SEM                           | 269.33 ± 1.764  |
| CD = 0.128                           | CV = 1.815      |
| 18. K$^+$ (mg/l)                     |                 |
| Mean ± SEM                           | 72.00 ± 1.25    |
| CD = 0.128                           | CV = 1.218      |
| 19. Mg$^{2+}$ (mg/l)                 |                 |
| Mean ± SEM                           | 262.00 ± 2.517  |
| CD = 0.128                           | CV = 1.883      |
| 20. SO$_4^{2-}$ (mg/l)               |                 |
| Mean ± SEM                           | 414.67 ± 1.667  |
| CD = 0.128                           | CV = 1.185      |
| 21. Inorganic P (mg/l)               |                 |
| Mean ± SEM                           | 0.190 ± 0.006   |
| 22. Particulate P (mg/l)             |                 |
| Mean ± SEM                           | 1.200 ± 0.000   |
| CD = 0.128                           | CV = 18.306     |
| 23. Total Dissolved P (mg/l)         |                 |
| Mean ± SEM                           | 1.100 ± 0.000   |
| CD = 0.128                           | CV = 3.280      |
| 24. Total Kjeldhal P (mg/l)          |                 |
| Mean ± SEM                           | 2.150 ± 0.010   |
| CD = 0.128                           | CV = 1.579      |
| 25. NH$_3$-N (mg/l)                  |                 |
| Mean ± SEM                           | 1.240 ± 0.025   |
| CD = 0.128                           | CV = 3.502      |
| 26. NO$_3$-N (mg/l)                  |                 |
| Mean ± SEM                           | 31.67 ± 1.202   |
The physico-chemical analysis for city and industrial effluents (Table 1 and Graphs 1a & 1b) was done in respect to water colour, odour, transparency, turbidity, temperature, pH, total alkalinity, free CO$_2$, DO, BOD, COD, TSS, TDS, Cl$^-$, Ca$^{2+}$, Na$^+$, K$^+$, Mg$^{2+}$, SO$_4^{2-}$, inorganic PO$_4^{3-}$, particulate PO$_4^{3-}$, total dissolved PO$4^{3-}$, total Kjeldhal PO$4^{3-}$, NH$_3$-N, NO$_3$-N, total Iron and heavy metals (Hg, Cr, Cd, Pb and As) as per methods described Parashar et al. [2]. Significant differences were noticed among all the parameters at 1% level of probability except heavy metals Hg and as when it was found to be significant at 5%. It is an effort and aims at detailed study of potential water quality problems in the light of industrial and urban development in Mathura with an attempt to see further its impact on plant growth and development especially agricultural crops of the region so that the quality of city and industrial effluent water of Yamuna River is best utilized for irrigation to raise higher crop yield.

For these studies two important crops of Mathura region, one legume crop (Mustard - *Brassica campestris* L; family Brassicaceae) and another cereal crop (Wheat - *Triticum aestivum* L; family Poaceae/Gramineae), were taken for screening and detailed physiological and biochemical studies. Seeds of the material involved in the present study were procured from the Agriculture Research Centre Raya, Mathura (UP) India.

The screening of crops was carried out after Garrard’s Technique Garrard [8] as modified by Sarin & Rao [9], Sharma [10] wherein germination percentage of the two crops was recorded. Observations on the influence of Stress I (Effluent) in the concentrations of 25, 50, 75, 100 (%); Stress II (NaCl salinity) at 4, 8, 12, 16 (dsm-1) of salt solution; Stress III (Heavy metal HgCl2) at 50, 100, 200, 300 (ppm) and the controls (distilled water grown) were recorded at 24 hours interval from 24 hours after sowing up to the end of 120 hours. Germination percentage at each interval in different treatment concentration levels and controls was observed. For this purpose 650 seeds in thirteen Petri dishes with 50 seeds in each Petri dish per treatment (controls and the three treatments with four concentrations) were allowed to grow on moistened filter paper in BOD Incubator at 25± 2 °C. All results with three replicates were analyzed by ‘Analysis of Variance’ (ANOVA) by using completely randomized design (CRD). Critical differences at 1 and 5 percent probability were calculated wherever the results were significant.

**Observations and Results**

Certified seeds of the two major local varieties of a legume (Mustard) and a cereal (Wheat) crop were screened for their relative tolerance to the three types of environmental stresses viz., Stress I (City & industrial effluents); Stress II (Saline water as sodium chloride NaCl) and Stress III (Heavy metal mercury as HgCl2) under varying concentration levels viz., 0, 25, 50, 75 & 100 percent (Effluents); 0, 4, 8, 12 & 16 EC dsm-1 (Salinity) and 0, 50, 100, 200 and 300 ppm (Heavy Metal). Distilled water was used as control in all the three types of environmental stress treatments. Observations on percent germination were recorded
at 24 hours interval from 24 hours after sowing up to the end of 120 hours. It was felt necessary to undertake relative tolerance behaviour of the two major crops of the Mathura Region (Cereal crop Wheat and Legume crop Mustard) to three types of environmental stresses i.e.,

a. Stress I
b. Stress II
c. Stress III under varying concentration levels in order to assess agricultural productivity under different stresses, as in the effluents analyzed, Na+ and Cl- ions and heavy metal Hg were also found in varying proportions Parashar et al. [2], which have been studied in combination with other parameters in effluents and individually having comparative deleterious effects on crop growth essential for using effluents in proper dilutions for increasing crop productivity and abating pollution load of River Yamuna.

Interestingly it has been observed that with increasing stress seed germination is delayed as well as reduced. There was also a differential response in percentage germination and tolerance to different types of stresses with respect to crops grown. It was, therefore, proposed to screen out further and make detailed physiological and biochemical studies on the selected crops to assess their relative tolerance to the three types of environmental stresses.

Table 2: Effect Of Different Levels Of Treatment Exposure On Germination Percentage In The Two Crops (Treatment X Concentration X Seedling Age) Mean Table.

| Crops     | Treatment | Concentration Level | 24hrs | 48hrs | 72hrs | 96hrs | 120hrs |
|-----------|-----------|---------------------|-------|-------|-------|-------|--------|
| Wheat     | Control (0%) | 0.37 | 52.017 | 67.947 | 86.947 | 91.35 |
|           | 25%       | 0.347 | 35.283 | 58.963 | 75.297 | 84.3  |
|           | Effluent  | 50% | 0.43 | 38.883 | 71.897 | 86.897 | 95.233 |
|           |           | 75% | 0.107 | 25.5 | 38.45 | 52.453 | 65.453 |
|           |           | 100% | 0 | 11.617 | 30.6 | 38.34 | 47.01 |
|           | Control (0 EC) | 0.37 | 52.017 | 67.947 | 86.947 | 91.35 |
|           | 4EC       | 0.247 | 25.283 | 57.297 | 65.297 | 74.3  |
|           | Salinity  | 8EC | 0.03 | 18.883 | 45.23 | 56.897 | 65.233 |
|           | 12EC      | 0.007 | 15.5 | 35.45 | 42.453 | 45.453 |
|           | 16EC      | 0 | 8.95 | 28.6 | 35.673 | 37.01 |
|           | Control (0 ppm) | 0.37 | 52.017 | 67.947 | 86.947 | 91.35 |
|           | 50 ppm    | 0.073 | 15.283 | 25.847 | 33.797 | 43.717 |
|           | Heavy Metal | 100 ppm | 0.017 | 8.883 | 22.05 | 33.767 | 34.417 |
|           | 200 ppm   | 0.003 | 5.167 | 10.783 | 15.45 | 15.45 |
|           | 300 ppm   | 0 | 1 | 1.333 | 1.667 |
|           | Control (0%) | 0.25 | 33.267 | 62.727 | 77.133 | 88.5  |
|           | 25%       | 0.323 | 37.987 | 60.847 | 77.517 | 88.183 |
|           | Effluent  | 50% | 0.34 | 46.617 | 66.81 | 78.147 | 89.4  |
|           |           | 75% | 0.097 | 27.81 | 45.15 | 58.483 | 76.15 |
|           |           | 100% | 0 | 17.667 | 37.34 | 48.34 | 57.673 |
|           | Control (0 EC) | 0.25 | 33.267 | 62.727 | 77.133 | 88.5  |
|           | 4EC       | 0.243 | 32.987 | 57.847 | 66.517 | 80.85 |
|           | Salinity  | 8EC | 0.02 | 26.617 | 46.81 | 58.147 | 76.067 |
Stress I (Effluent)

There was no germination at all at 24 hours in both the crops Mustard and Wheat with 100% of Effluent conc. The lowest mean germination percentage (GP) of 0.097% was observed in the legume crop Mustard with 75% Effluent conc. at 24 hours whereas the highest mean GP (95.233%) was recorded in the cereal crop Wheat with 50% of Effluent conc. at 120 hours. In Control sets, crop Wheat showed more GP at all the durations except at 24 hours when it was a little bit lower (0.347% in Wheat and 0.323% in Mustard). With 50% Effluent conc. the GP showed a reverse trend as higher GP was observed in Wheat at all the durations except at 48 hours when it was found to be 7.734% higher in Mustard. Again with 75% and 100% Effluent conc., Mustard showed better GP than Wheat except at 24 hours with 75% Effluent conc. in Wheat when it was (0.107%) more than Mustard (0.097%).

Stress II (Salinity)

Likewise, with Salinity there was no germination at all at 24 hours in both the crops Mustard and Wheat with 16 EC of Salt conc. The lowest mean GP (0.007%) was observed in both the crops Mustard and Wheat with 12 EC of Salt conc. at 24 hours whereas the highest mean GP (91.350%) was recorded in the cereal crop Wheat in Controls at 120 hours. In Control sets, the crop Wheat showed more GP at all the durations from 24 hours to 120 hours but with 4 EC of Salt conc. higher GP was observed in Mustard at all the durations except at 24 hours when it was a little bit lower (Wheat 0.247% and Mustard 0.243%). With 8 EC of Salt conc. GP showed a reverse trend as higher GP was observed in Mustard at all the durations except at 24 hours when it was found to be 0.01% higher in Wheat. Again with 12 and 16 EC of Salt conc. the crop Mustard showed better GP than Wheat except at 24 hours with 12 EC of Salt conc. when it happened to be similar (0.007%) in both the crops.

Stress III (Heavy metal)

As also with 100% Effluent conc. and 16 EC of Salinity conc. likewise, there was no germination at all in the two crops Mustard and Wheat with the higher Heavy metal conc. of 300 ppm at 24 hours but unlike the former treatments with the Heavy metal treatment the crops did not show any germination at 48 hours also under 300 ppm. The lowest mean GP (0.003%) was observed in both the crops at 24 hours with 200 ppm Heavy metal conc whereas the highest mean GP (91.350%) was recorded in the cereal crop Wheat with Controls at 120 hours. In Control sets Wheat showed more GP than Mustard at all the durations from 24 hours to 120 hours but with 50, 100, 200 and 300 ppm Heavy metal conc. higher GP was observed in Mustard at all the durations except at 24 hours when it was a little bit lower (0.017% in Wheat and 0.010% in Mustard) and with 200 ppm GP in both the crops showed no difference from 24 hours - 120 hours but with 25% Effluent conc. higher GP was observed in the crop Mustard at all the durations except at 24 hours when it was a little bit lower (0.347% in Wheat and 0.323% in Mustard). With 50% Effluent conc. the GP showed a reverse trend as higher GP was observed in Wheat at all the durations except at 48 hours when it was found to be 7.734% higher in Mustard. Again with 75% and 100% Effluent conc., Mustard showed better GP than Wheat except at 24 hours with 75% Effluent conc. in Wheat when it was (0.107%) more than Mustard (0.097%).
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(0.003% in both Wheat and Mustard). Mustard showed better GP than Wheat even at 300 ppm at 120 hours when it was nearly double (3.007% in Mustard and 1.667% in Wheat) and was more than double at 120 hours with 200 ppm (36.150% in Mustard and 15.450% in Wheat). Thus, highest average GP of 95.233% was observed in the crop Wheat in 50% of Effluent conc. at 120 hours while lowest GP of 1.000% was also observed in the crop Wheat in 300 ppm of Heavy metal conc. at 72 hours.

Table 3: Effect of Different Levels of Treatment Exposure on Germination Percentage in the two Crops (Percent over Control).

| Crops | Treatment | Concentration Level | Seedling Age |
|-------|-----------|---------------------|--------------|
|       |           |                     | 24hrs | 48hrs | 72hrs | 96hrs | 120hrs |
|       | Effluent  | Control (0%)        | 100%  | 100%  | 100%  | 100%  | 100%  |
|       |           | 25%                 | 93.784 | 67.83  | 86.778 | 86.602 | 92.282 |
|       |           |                     | (-6.216) | (-32.170) | (-13.222) | (-13.398) | (-7.718) |
|       |           | 50%                 | *116.216 | 74.751 | *105.813 | 99.942 | *104.250 |
|       |           |                     | (+16.216) | (-25.249) | (+5.813) | (-0.058) | (+4.250) |
|       |           | 75%                 | 30.836 | 49.022 | 56.588 | 60.328 | 71.651 |
|       |           |                     | (-69.164) | (-50.978) | (-43.412) | (-39.672) | (-28.349) |
|       |           | 100%                | 0      | 22.333 | 45.035 | 44.096 | 51.461 |
|       |           |                     | (-100.000) | (-77.667) | (-54.965) | (-55.904) | (-48.539) |
| Wheat | Salinity  | Control (0 EC)      | 100%  | 100%  | 100%  | 100%  | 100%  |
|       |           | 4EC                 | 66.757 | 48.605 | 84.326 | 75.1 | 81.336 |
|       |           |                     | (-33.243) | (-51.395) | (-15.674) | (-24.900) | (-18.664) |
|       |           | 8EC                 | 8.108 | 36.302 | 66.567 | 65.439 | 71.41 |
|       |           |                     | (-91.892) | (-63.698) | (-33.433) | (-34.561) | (-28.590) |
|       |           | 12EC                | 1.892 | 29.798 | 52.173 | 48.826 | 49.757 |
|       |           |                     | (-98.108) | (-70.202) | (-47.827) | (-51.174) | (-50.243) |
|       |           | 16EC                | 0      | 7.206 | 42.092 | 41.028 | 40.514 |
|       |           |                     | (-100.000) | (-82.794) | (-57.908) | (-58.972) | (-59.486) |
|       | Heavy Metal| Control (0 ppm)    | 100%  | 100%  | 100%  | 100%  | 100%  |
|       |           | 50 ppm              | 19.73 | 29.381 | 49.564 | 50.28 | 48.166 |
|       |           |                     | (-80.270) | (-70.619) | (-50.436) | (-49.720) | (-51.834) |
|       |           | 100 ppm             | 4.595 | 17.077 | 32.452 | 38.836 | 37.676 |
|       |           |                     | (-95.405) | (-82.923) | (-67.548) | (-61.164) | (-62.324) |
|       |           | 200 ppm             | 0.811 | 9.933 | 15.87 | 17.77 | 16.913 |
|       |           |                     | (-99.189) | (-90.067) | (-84.130) | (-82.230) | (-83.087) |
|       |           | 300 ppm             | 0      | 0     | 1.472 | 1.533 | 1.825 |
|       |           |                     | (-100.000) | (-100.000) | (-98.528) | (-98.467) | (-98.175) |
| Mustard | Effluent| Control (0%)        | 100%  | 100%  | 100%  | 100%  | 100%  |
|       |           | 25%                 | *129.200 | *114.188 | 97.003 | *100.498 | 99.642 |
|       |           |                     | (+29.200) | (+14.188) | (-2.997) | (+0.498) | (-0.358) |
|       |           | 50%                 | *136.000 | *140.130 | *106.509 | *113.315 | *101.017 |
|       |           |                     | (+36.000) | (+40.130) | (+6.509) | (+1.315) | (+1.017) |
|       |           | 75%                 | 38.8 | 83.596 | 71.979 | 75.821 | 86.045 |
|       |           |                     | (-61.200) | (-16.404) | (-28.021) | (-24.179) | (-13.955) |
|       |           | 100%                | 0      | 53.107 | 59.528 | 62.671 | 65.168 |
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Salinity

|            | Control (0 EC) | 4EC | 8EC | 12EC | 16EC |
|------------|----------------|-----|-----|------|------|
| Control    | 100%           | 100%| 100%| 100% | 100% |
| 8EC        | -8.000         | -8.000| -7.800| -13.763| -8.644 |
| 12EC       | 2.8            | 53.537| 61.35| 62.856| 74.746 |
| 16EC       | 0              | 45.09| 52.62| 60.078| 62.907 |

Heavy Metal

|            | Control (0 ppm) | 50 ppm | 100 ppm | 200 ppm | 300 ppm |
|------------|-----------------|--------|---------|---------|---------|
| Control    | 100%            | 100%   | 100%    | 100%    | 100%    |
| 50 ppm     | 44              | 61.082| 57.679 | 62.036 | 57.458 |
| 100 ppm    | 4               | 38.927| 42.741 | 49.456 | 52.053 |
| 200 ppm    | 1.2             | 16.464| 23.621 | 36.495 | 40.847 |
| 300 ppm    | 0               | 4.794 | 3.898  | 3.398  | 3.398  |

C. D. for Treatment x Concentration x Seedling Age: Wheat = 1.604; Mustard = 1.736 Values in parentheses are representing % change (Loss)/(gain +) from control

(Table 3, Graphs 3a & 3b) shows the effect of different levels of treatment concentration on GP as percent over control. Interestingly, stimulation has been observed in growth of both the crops as increased GP at moderate levels (25% and 50%) of Effluent conc. In the crop Mustard GP in 25% Effluent conc. showed a change in percent from Control at 24 hours (+29.200%), at 48 hours (+14.188%) and at 96 hours (+0.498%) respectively and in 50% Effluent conc. percent change from Control was observed to be at 24 hours (+36.000%), at 48 hours (+0.130%), at 72 hours (+0.509%), at 96 hours (+0.315%) and at 120 hours (+0.1017%) whereas in the crop Wheat GP only in 50% Effluent conc. Increased at 24 hours (+16.216), 72 hours (+5.813) and 120 hours (+4.250).

Besides, both the crops Mustard and Wheat did not show any seed germination at all in 100% (Effluent), 16 dsm-1 (Salinity) and 300 ppm (Heavy metal) concentrations at 24 hours and in 300 ppm (Heavy metal) conc. at 48 hours also. Further, it was observed that 75% (Effluent), 12 dsm-1 (Salinity) and 200 ppm (Heavy metal) concentrations for three types of stresses and...
also 72 hours of germination were found to be quite critical for the two crops (Table 4 and Graph 4a & 4b), therefore, on the basis of percent over control at 72 hours with 75% (Effluent), 12 dsm-1 (Salinity) and 200 ppm (Heavy metal) concentrations respectively the germination percentage in the two crops showed the following trend:

Table 4: Effect of Different Levels of Treatment Exposure on Germination Percentage In The Two Crops (Data Recorded After 72 Hours Of Presoaking The Seeds In Test Solutions).

| Crops  | Treatment | Concentration Level | Germination percentage | Percent over control | Over control |
|--------|-----------|---------------------|------------------------|---------------------|-------------|
| Wheat  | Control   | DW                  | 67.947                 | 100%                | 100%        |
|        | Effluent  | 75%                 | 38.45                  | 56.59%              | (-43.412)   |
|        | Salinity  | 12EC                | 35.45                  | 52.17%              | (-47.827)   |
|        | Heavy Metal | 200 ppm         | 10.783                 | 15.87%              | (-84.130)   |
| Mustard| Control   | DW                  | 62.727                 | 100%                | 100%        |
|        | Effluent  | 75%                 | 45.15                  | 71.98%              | (-28.021)   |
|        | Salinity  | 12EC                | 38.483                 | 61.35%              | (-38.650)   |
|        | Heavy Metal | 200 ppm         | 14.817                 | 23.62%              | (-76.379)   |

C. D. for Treatment x Concentration x Seedling Age: Wheat = 1.604; Mustard = 1.736

Graph 4a: Effect of Different Levels of Treatment Exposure on Germination Percentage in the two Crops. (Data Recorded After 72 Hours of Presoaking the Seeds in Test Solutions). (Treatment X Concentration X Seedling Age)

Effluent: Mustard [71.979%* (-28.021)], Wheat [56.588%* (-43.412)]

Salinity: Mustard [61.350%* (-38.650)], Wheat [52.173%* (-47.827)]

Graph 4b: Effect of Different Levels of Treatment Exposure on Germination Percentage in the two Crops. (Data Recorded After 72 Hours of Presoaking the Seeds in Test Solutions). (Treatment X Concentration X Seedling Age)

Heavy Metal: Mustard [23.621%* (-76.379)], Wheat [15.870%* (-84.130)]

*Values are arithmetic mean of three replicates; Values in parentheses are representing % change from control

Table 5: * Anova Table* Germination Percentage in the Two Crops.

| Crop   | Source of variation | DF | SS       | MSS       | F-value  |
|--------|---------------------|----|----------|-----------|----------|
| Wheat  | Factor A (Treatment) | 2  | 20106.36 | 10053.18** | 10173.74 |
|        | Factor B (Concentration) | 4  | 50431.47 | 12607.87** | 12759.07 |
|        | Factor C (Duration)   | 4  | 103846.7 | 25961.67** | 26273.02 |
|        | Factor A X B          | 8  | 6763.03  | 845.38**  | 855.52   |
**Significant at 1% Level of Probability**

Table 6: Effect of Different Levels of Treatment and Concentration Exposure on Germination Percentage in the Two Crops (Treatment X Concentration).

| Crop    | Treatment | Concentration Level | Mean for Treatment |
|---------|-----------|---------------------|--------------------|
|         |           | Conc. 1 | Conc. 2 | Conc. 3 | Conc. 4 | Conc.5 |
| Wheat   | Effluent  | 59.726  | 50.838  | 58.668  | 36.393  | 25.513 | 46.228   |
|         | Salinity  | 59.726  | 44.485  | 37.225  | 27.773  | 22.047 | 38.57    |
|         | Heavy metal | 59.726 | 27.35   | 19.827  | 9.371   | 0.8    | 23.415   |
|         | Mean for concentration | 59.726 | 40.891  | 38.583  | 24.512  | 16.12  |           |

Analysis of Variance (ANOVA) Table - Percent Germination (Table 5 and Graph 5a & 5b) shows that all the main effects viz., Treatment (A), Concentration (B) and Duration (C) with their interactions (A x B, A x C, B x C, A x B x C) were highly significant at 1% level of probability.

This is also evident from the (Table 2) wherein Analysis of Variance (treatment, concentration and duration), (Table 6) (treatment x concentration), (Table 7) (treatment x seedling age) and (Table 8) (concentration x seedling age) the effect of different levels of concentration exposure and seedling age on germination percentage in the two crops respectively have been depicted. The final interaction was also observed to be statistically significant.

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A review of the (Table 6 & Graph 6) (treatment x concentration) shows that the crop Mustard had better GP than the crop Wheat in all the three types of treatment, that is, the highest mean GP in the two crops (Mustard 47.038% and Wheat 46.228%) was when sown in Effluent followed by Salinity where it was 41.157% in Mustard and 38.257% in Wheat while lowest was in Heavy Metal treatment (Mustard 25.391% and Wheat 23.415%). Regarding concentration of the treatments, highest mean GP was found in Controls (Wheat 59.726% and Mustard 52.375%) followed subsequently in Conc. 1 (25% Effluent; 4 dsm-1 Salinity; 50 ppm Heavy Metal) where in the two crops it was observed to be Mustard 43.907% and Wheat 40.891%; Conc. 2 (50% Effluent; 8 dsm-1 Salinity; 100 ppm Heavy Metal) it was observed to be Mustard 40.864% and Wheat 38.583%; Conc. 3 (75% Effluent; 12 dsm-1 Salinity; 200 ppm Heavy Metal) it was observed to be Mustard 30.828% and Wheat 24.512% and lastly in the maximum concentration i.e., Conc. 4 (100% Effluent; 16 dsm-1 Salinity; 300 ppm Heavy Metal) it was observed to be Mustard 21.337% and Wheat 16.120%. Thus, the three treatments and their five concentrations each showed better mean GP in the legume crop Mustard than the cereal crop Wheat except in the Controls where in Wheat it was more than that in Mustard.

**Table 7: Effect of Different Levels of Treatment Exposure and Seedling Age on Various Growth and Biochemical Parameters in the Two Crops (Treatment X Seedling Age).**

| Crop    | Treatment | Seedling age (hours) | Mean for Treatment |
|---------|-----------|----------------------|--------------------|
|         |           | 24 hrs   | 48 hrs | 72 hrs | 96 hrs | 120 hrs |                |
| Wheat   | Effluent  | 0.251    | 32.66  | 53.57l | 67.987 | 76.669  | 46.228          |
|         | Salinity  | 0.131    | 24.127 | 46.905 | 57.453 | 62.669  | 38.257          |
|         | Heavy metal | 0.093 | 16.27   | 27.091 | 36.243 | 37.377  | 23.415          |
|         | Mean for Seedling age | 0.158 | 24.352 | 42.522 | 53.894 | 58.905  |
|         | C.D. for Treatment = 0.321 | C.D. for Seedling age = 0.717 | C.D. for Treatment x Seedling age = 0.717 |
| Mustard | Effluent  | 0.202    | 32.69  | 54.575 | 67.924 | 79.821  | 47.038          |
|         | Salinity  | 0.104    | 25.136 | 47.775 | 59.324 | 73.448  | 41.157          |
|         | Heavy metal | 0.075 | 14.403 | 28.708 | 38.857 | 44.915  | 25.391          |
|         | Mean for Seedling age | 0.127 | 24.069 | 43.686 | 55.368 | 66.061  |
|         | C.D. for Treatment = 0.347 | C.D. for Seedling age = 0.448 | C.D. for Treatment x Seedling age = 0.776 |

**Graph 6:** Effect of Different Levels of Treatment and Concentration Exposure on Germination Percentage in the two Crops. (Treatment X Concentration)

**Graph 6:** Effect of Different Levels of Treatment and Concentration Exposure on Germination Percentage in the two Crops. (Treatment X Concentration)
Likewise, a review of the (Table 7 & Graph 7) (treatment x seedling age) shows that the crop Mustard had better GP than the crop Wheat in all the three types of treatment as shown below for the interaction of Treatment x Concentration. Regarding seedling age, highest GP was found at 120 hours (Mustard 55.368% and Wheat 53.894%); at 72 hours it was observed to be Mustard 43.686% and Wheat 42.522%; at 48 hours it was observed to be Mustard 24.069% and Wheat 24.352% and lastly at the initial duration of 24 hours it was observed to be Wheat 0.158% and Mustard 0.127%. Thus, the three treatments and five durations also showed better mean GP in the legume crop Mustard than the cereal crop Wheat except at 24 hours where in Wheat comparatively better seed sprouting took place.

Lastly, review of the (Table 8 & Graph 8) (concentration x seedling age) shows that still the crop Mustard had better GP than the crop Wheat in all the four concentrations except Controls where it happened to be more in Wheat. Regarding seedling age, as shown below Wheat had comparatively better seed germination at 24 and 48 hours whereas Mustard showed better mean GP at the increasing seedling age 72, 96 and 120 hours.

Thus, in general the GP decreased with increasing concentration levels of the three stresses, i.e., Effluent, Salinity and Heavy metal. The differential behaviour of the genotypes in relation to the three types of stresses as well as with seedling age is also evident from (Table 2) as described earlier under the interactions of the main factors. Interestingly, as shown in the (Table 3) stimulation has been observed in growth of both the crops as increased GP at moderate levels (25% and 50%) of Effluent conc. This stimulation in growth may be attributed to the
nutritional supplementation at low concentration (25% and 50% in Mustard and 50% in Wheat) of salts present in the Effluents. Besides, seeing overall results Heavy metal proved to be more toxic than Effluents and Salinity stresses for seed germination at higher concentrations of 75% and 100% (Effluent), 12 and 16 dm⁻³ (Salinity) and 200 and 300 ppm (Heavy metal). However, significant differences were noticed in the germination percentage (GP) of the two crops studied with the legume crop Mustard showing better performance in GP than the cereal crop Wheat in the three types of Stresses as compared to Controls. Conclusively, it can be inferred that with increasing seeding age, seed germination increased in the two crops whereas with increase in treatment concentrations, GP was decreased except at lower concentrations in the Effluent Treatment, seed germination showed an enhancement over the Controls.

**Discussion**

**Effluent effect on crop plants**

Environment is deteriorating at very fast rate. Unplanned and unsystematic urbanization and industrialization are giving rise to serious problems of pollution. With the increasing urbanization and industrialization the disposal of sewage effluents on agricultural land is becoming a serious problem all over the world. The composition of sewage sludge changes with the type of industries discharging their effluents into the sewer system. The present age is an era of rapid industrialization which has revolutionized the human life. It has facilitated human life in many ways Khanna & Ram Babu [11]. Reuse of wastewater effluent is currently receiving more attention because of water shortages. Use of treated wastewater effluent can be a new source of water Naddafi [12]; Parashar [7]; Snehlata [5]. Traditionally, domestic wastewater was used as fertilizer in agriculture or as soil conditioner in some parts of Asia. Sewage Waste Management by Irrigating Crop plants for their sustainable improvement was projected by Sharma et al. [13]. The continuous use of industrial effluents by people in the adjoining area has become a common practice which results in accumulation of industrial pollutants and toxic metals in soil to such a level that may become phytotoxic and hazardous for the life of animal and human beings Sharma [1], Singh [14], Parashar [7], Parashar et al. [2]. The recurring inception of the effluents in soil may alter the soil surface colour and can also block the soil pores in the field. The physico-chemical analysis of soils [Electrical Conductivity, Hydrogen Ion Concentration, Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC), Total Nitrogen, Total Organic Matter and Total Organic Phosphorous] irrigated with effluents from the polluted sites exhibited significantly higher values for almost all the parameters during the entire period of investigation Parshar et al. [2]. Pollution of River Yamuna at Mathura has been taken up by Sharma [6], Sharma [15], Parashar [7], Parashar et al. [16], Singh [17] studied physico-chemical investigation of industrial effluent and its effect on germination of Triticum aestivum (wheat). Physico-chemical analysis of industrial effluents merging in Yamuna River at Mathura effect of irrigation with contaminated Yamuna River Water on seed germination and growth of Sorghum vulgare and Triticum aestivum L were studied by Sharma [1], Parashar et al. [18]; wheat and mustard Parashar [7]; wheat, barley, mustard and bakla Snehlata [9]. The polluted effluent water first of all affects the first step of plant life i.e., germination of seeds, by inhibiting enzyme action Sharma [1]; Parashar [7]; Snehlata [5]. Presence of heavy toxic metals in effluents caused plasmolysis in test plant Triticum aestivum Singh [14], Mishra et al. [19], Sharma [1], Parashar [7], Snehlata [5] reported that polluted water also contains beneficial elements (N, P, K) as well as toxic metals (Cr, Ni, Zn, Cd, Pb, Hg, Pb and As). Besides, increase in NH₄⁺-N concentration in effluent due to the mineralization of easily decomposable nitrogenous substances present in the sludge resulting in the release of NH₄⁺-N and later the decrease in the concentration of NH₄⁺-N may be due to plant uptake and reduced rate of release of NH₄⁺-N from sludge Singh et al. [20], fixation and volatilization losses Nagarajah [21]. The effluents along with N, P, K released higher amounts of NH₄⁺-N. Besides, NO₃⁻-N recorded due to withholding of water and conversion of NH₄⁺-N to NO₃⁻-N (mineralization). The NO₃⁻-N concentration may be due to immobilization and de-nitrification by general soil micro-flora. A higher NO₃⁻-N concentration recorded may also be caused by oxidation of NH₄⁺-N to NO₃⁻-N in the rhizosphere, resulting due to the excess proliferation of plant roots rendering the soil more oxidative Sakai [22]; Smith & Delaune [23]. Thus, the present study revealed that the higher N content in the effluents released significantly higher N fraction in the soil through decomposition. This material can be considered as an organic manure and soil amendment if properly treated and diluted before used for irrigating crops. The addition of sludge to agricultural land has been reported to increase the yields of many plants Sharma [1]; Unnamalai et al. [24]; Snehlata [5]. In the present analysis investigation was undertaken to assess the effect of mixed effluent on water quality of industrial area of Yamuna River at Mathura and its impact on germination of the crop plants, Mustard and Wheat usually cultivated in this area. The detrimental effects of water pollution due to discharge of industrial effluents have been well documented in various crops Sharma [1]; Dalai & Mohanty [25] suggesting various degrees of dilution of effluents beneficial to the crops. The studies conducted by various workers Kadioglu & Algur [26]; Tiwari et al. [27]; Muthukumar & Arokiasamy [28]; Subramani et al. [29]; Sharma [1]; Dalai & Mohanty [30] revealed that the lower effluent concentration stimulates the plant growth whereas inhibiting at higher concentrations as also shown in the present work. The studies conducted by Pragarasam & Kannabiran [31] on Vigna mungo with distillery effluent inhibited the growth of the seedlings. A large number of reviews Kannabiran & Pragarasam [32]; Kumar [33]; Chidambaram et al. [34]; Kannan [35]; Pragarasam and Kannabiran [31], Pragarasam & Kannabiran [36,37]; Mishra & Pandey [38]; Sharma [1] are available with regards to the effect of city and industrial effluents in the laboratory.
experimentation with various commonly cultivated crop plants. The effects of industrial effluent on germination of seeds were attributed to the presence of bio-toxic substances which alters the seed-water interaction necessary for triggering enzyme activity Baruah & Das [39]; Sharma [1]. Studies conducted by Kannabiran & Pragasam [32], Chidambaram et al. [34], [36,37] reported that sugar mill effluent severely affected the germination and seedling growth of various seeds which also confirms our observations. Studies on the impact of textile waste water on seed germination and growth development of *Vicia faba* L. and were undertaken by Sharma et al. [38]. Further studies on Impact of paper mill effluent on seed germination and seedling growth of *Cymompis tetragonoloba* L and *Vigna radiata* L. were also performed by Sharma et al. [39,40]. Impact of industrial effluent on seed germination and seedling growth of *Citrus vulgaris* var. and impact of textile wastewater on seed germination and growth development on *Lycopersicon esculentum* esculentum were also studied Sharma et al. [41]. Sharma et al. [42] reported the impact of paper mill Effluent on seed germination and seedling growth of *Vigna radiata* L in Sanganer Region at Jaipur (Raj) India.

**Salinity effect on crop plants**

Soil salinity is a matter of global concern for stepping up agricultural production. Crop growth and its productivity are hampered on such lands on account of several unfavourable soil factors Bohnert et al. [43]. Saline soils have the problem of high soluble salts Sharma et al. [44]; Sharma & Baijal [45]; Babu et al. [46] creating a condition of physiological drought which limits plant growth by inhibiting nutrient and water uptake by plants [7,47-58]. Sodium (Na+) and chloride (Cl-) are among the most common ions found in excess in saline soils and some plant species are especially sensitive to one or both of these ions [59-65]. With many species, however, the ionic composition seems to be less important than the total amount of salt. This non-specific suppression of growth by salt has been interpreted as an osmotic phenomenon Bernstein & Hayward [66]. A general suppression of growth is probably the most common plant response to salinity. Salinity suppresses plant growth. The suppression increases as the salt concentration increases [Maas and Nieman, 1978]. The depressing effect has been generally attributed to the increased soil-moisture-stress or to specific toxic effect of the ions as a result of their absorption and accumulation Bhardwaj [67]. Soil salinity adversely affects the seed germination and various crops as well as their varieties exhibit a differential behaviour at different degrees of salinity during germination. Salinity has been shown to affect the time and rate of germination, the size of plants, branching and leaf size and overall plant anatomy Poljakoff-Mayber [68]. The delayed and decreased germination has been observed by many workers in different plants. Not only that different plants exhibit a differential response to salinity during germination but also their varieties show wide differences in their salt tolerance as observed in barley, oats, wheat, alfalfa, sugar beets, corn and field peas [69-74] in barley, sugar beet, corn, kidney bean and alfalfa; Ayers et al. [75] in barley; Kim [76], in different vegetable crops; Bhardwaj & Rao [77] in gram; Mehta & Desai [78] in pearl millets, tobacco, cotton, bean, tomato, gram, cabbage and pea; Dewey [1960] in *Agropyron sp*.; Bernstein [79] in various fruit crops during germination and seedling stage; Wahhab [1961] in wheat, paddy, maize and barley; [80-86] in various leguminous crops; Maliwal [87], in maize; in rice Pearson et al. [88]; bajora Abichandani & Bhatt [89]; in sorghum Abichandani & Bhatt [89]; Maliwal [87]; Ogra & Baijal [80], Nauhbar [55]; Yadav [54]; on wheat, Nauhbar [55]; in legumes. In general, it seems that germination or seedling stage is the most sensitive stage to saline water. Some varieties are more tolerant at germination as compared to others and the varietal differences are so wide that some varieties may fail to give good germination even at an EC of 4 dsm⁻¹ of water whereas the others may do well up to 20 dsm⁻¹ Gupta [18]. It is usual that with increasing salinity, germination is delayed as well as reduced. There is also differential response in percentage of germination with respect to varieties. The reduction in germination under saline conditions could be due to increased osmotic pressure of the soil solution. Consequently the absorption rate diminishes causing moisture stress in the seed. It could also be due to the influx of ions in quantities large enough to make them toxic to the seed embryo.

**Heavy metal effect on crop plants**

Mercury is a widely distributed environmental pollutant, able to induce toxicity in living organisms, including higher plants. It is an environmental pollutant which is mainly supplied via anthropogenic sources to the soil. It is harmful because of its toxicity, mobility, bioaccumulation, methylation process and transport in the atmosphere Parashar [7]; Saraswata [4]; Singh [14]; Gautam [57]; Rodriguez et al. [82]. It is one of the best known toxic metals discharged from human activities. The global rise in mercury pollution by anthropogenic activities may have risen by three to four folds in this century, but the seriousness of the problem at local levels is many times greater. The environmental protection agencies have expressed increasing concern over the release of mercury to the environment in the past couple of years Jamal et al. [83]. Mercury pollution of the environment and its impact on crop plants has been studied by Parashar et al. [16]. There are studies about the response of crop species to heavy metals reporting mechanisms that are responsible for their tolerance or sensitivity Shripanahi & Anderson [90]; Ernest [85]; Hall [86]; Watanabe & Osaki [87]; Mahmood et al. [88]; Vitorrella et al. [89]. Mercuric chloride (HgCl₂) is dominant among all mercury forms. Shripanahi and Anderson [1986] found elevated levels of cadmium, lead and mercury in the upper layer of soil following long term application of municipal wastewater which resulted in the accumulation of toxic levels of these metals in the vegetables grown in these areas. The toxic effect of mercury on germination, growth and yield has been studied on different plants Parashar [7]; Mukherjee and De [34]; Saraswata et al. [50]; Saraswata [51]; Gautam [71]; Jamal et al. [83]; Singh [86]; Vizarova et al. [91]; Varshneya [92] have studied the phytotoxicity.
of heavy metal mercury on germination and early seedling growth in wheat. Our results showed that seed germination of both the crops was enhanced at all the concentrations of mercury as compared to untreated control. Mercury treatment could break the seed dormancy and enable seeds to germinate [83]. Excessive mercury ions in soil also decreased metabolic contents of seedlings in various crop plants Vizarev et al. [91]. Kasimuthu & Subramanian [92] found reduction in seed germination. Results of the present study clearly indicate reduced germination in the two crops in response to treatments with increasing concentrations of heavy metal HgCl$_2$. Although mercury showed sharp decline in germination performance, data presented here also show significant decrease in germination under the influence of high concentration of mercury with respect to time in the two crops which concomitantly decrease in seedling vigor (observed in terms root and shoot length) indicated that the metabolic system of the seed could be modified by a very small concentration of mercury. Previous workers have speculated direct effect of heavy metals on various biomolecules decreased hydrolysis of endospermic food reserves, inhibition of various hydrolytic enzymes Parashar [5]; Singh [13]; Gautam [80]. Therefore, the set pattern of decreases in tolerance with mercury was observed as: Wheat > Mustard. Seeds treated with Hg showed lower germination percentage. Several workers Parashar [5]; Singh [13]; Gautam [80] reported that inhibition in seed germination at higher concentration of heavy metals was mainly caused by ion toxicity. Ion toxicity is associated to changes in cellular permeability, inhibition of protein activity and/or direct toxicity to the embryo and seedling Parashar [5]; Singh [13]; Gautam [80]. Reduction in germination of seeds in presence of Hg has been reported in rice [Mukherjee and Mitra, 1976] and also in other plants Parashar [5]; Singh [13]; Gautam [80]. Results also showed that mustard crop was more tolerant for heavy metal Hg in comparison to other crop wheat [93-100]. The heavy metal’s accumulation in the shoot may also lead to increased phenolic compounds that may be responsible for inhibition of germination. These observations clearly show that the crop mustard suffered lesser than the other crop wheat i.e., the former crop is more tolerant than the later crop, therefore on the basis of their relative tolerance the two crops tested can be placed in the descending order of their heavy metal tolerance as follows: Mustard > Wheat [100-106].

**Concluding Remarks**

The aim of this research is to investigate comparative effects of Effluents, Salinity and Heavy metal stresses on seed germination in the two important crops wheat and mustard commonly cultivated in Mathura region Uttar Pradesh, India. The effects of three environmental stresses were tested at germination stage of these crops as this is the key event for the establishment of plants under any prevailing environmental conditions. In general, the germination percentage with increasing concentration levels of the three stresses, i.e., Effluent, Salinity and Heavy metal showing differential behavior of the two genotypes in relation to the three types of stresses as well as with seedling age. Interestingly, stimulation has been observed in growth of both the crops as increased germination percentage at moderate levels of Effluent concentration. This stimulation in growth may be attributed to the nutritional supplementation at lower concentration of salts present in the Effluents. Besides, seeing overall results Heavy metal proved to be more toxic than Effluents and Salinity stresses for seed germination at higher concentrations of 75% and 100% (Effluent), 12 and 16 dsm$^{-1}$ (Salinity) and 200 and 300 ppm (Heavy metal). However, significant differences were noticed in the germination percentage of the two crops studied with the legume crop Mustard showing better growth performance than the cereal crop Wheat in the three types of Stresses as compared to Controls. The higher level of heavy metal Hg caused complete inhibition of seed germination. Therefore, Mustard crop was found to be more tolerant than Wheat crop for effluents, salinity as well as heavy metals. Thus, identification of plant species which can resist and clean-up metals from soils is required to improve phyto-remediation technologies. Moreover, plants have been proposed as bio-monitors of soil contamination but also as biomarkers of the environmental risk of pollutants.

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