

### **Supplementary Information**

#### **Nano-micronutrients [ $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> (iron) and ZnO (zinc)]: Green preparation, characterization, agro-morphological characteristics and crop productivity studies in two crops (rice and maize)**

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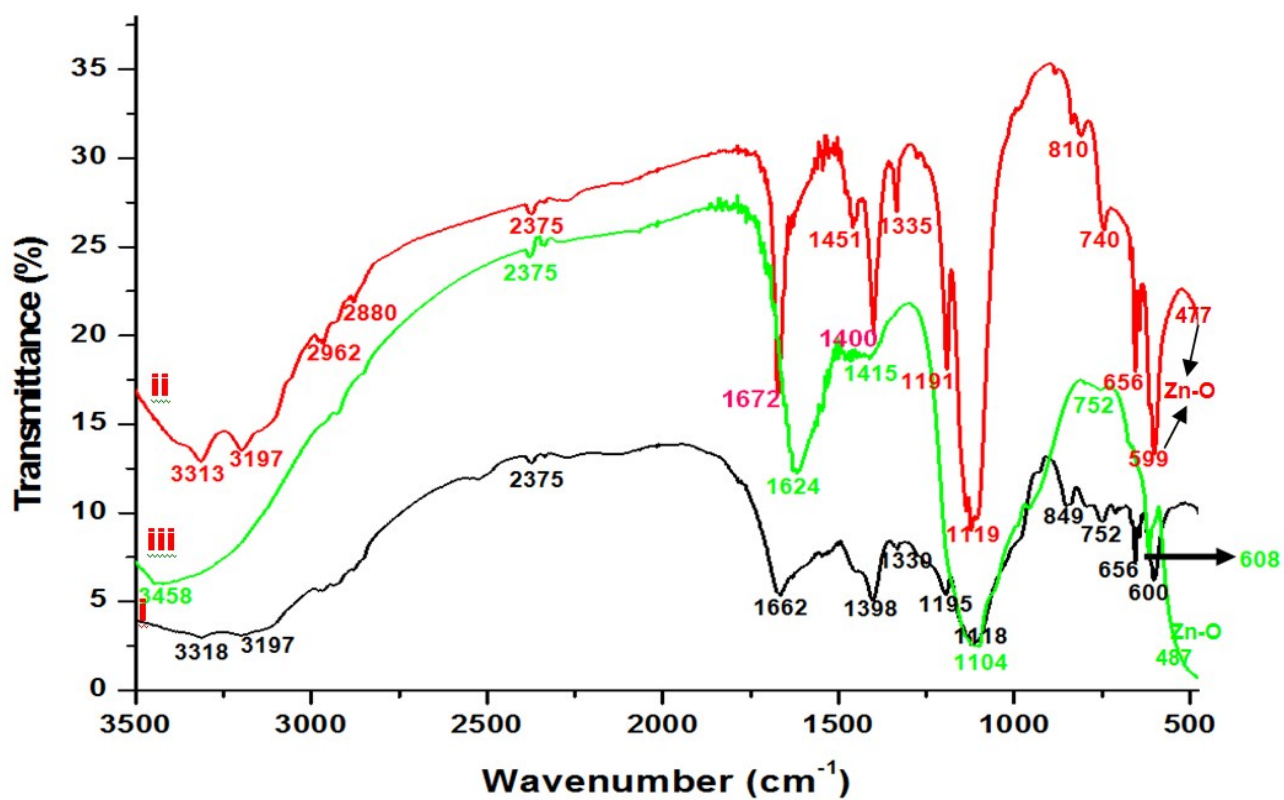
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Figure S1 shows edible green alga *Ulva lactuca*



Figure S2 shows the FTIR spectrum of i) green alga *Ulva lactuca*; ii)  $\gamma$ - $\text{Fe}_2\text{O}_3$  and iii) ZnO nanoparticles synthesized using *Ulva lactuca*



**Table 1a.  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> nanopriming on seed germination and seedlings parameters in rice under *in vitro* laboratory condition (14<sup>th</sup> day)**

| Experiments       | Germination (%)         | Shoot length (mm)       | Root length (mm)         | Seedling length (mm)     | Vigor index | Initial fresh weight (gm) | After dry weight (gm)     |
|-------------------|-------------------------|-------------------------|--------------------------|--------------------------|-------------|---------------------------|---------------------------|
| Control           | 89 ± 1.13 <sup>b</sup>  | 97 ± 0.16 <sup>b</sup>  | 158 ± 1.81 <sup>bc</sup> | 255 ± 3.99 <sup>c</sup>  | 22695       | 2.7 ± 0.05 <sup>ab</sup>  | 0.39 ± 0.00 <sup>bc</sup> |
| 100 ppm           | 100 ± 1.41 <sup>a</sup> | 98 ± 1.79 <sup>b</sup>  | 156 ± 3.17 <sup>c</sup>  | 254 ± 4.63 <sup>cd</sup> | 25400       | 2.2 ± 0.02 <sup>e</sup>   | 0.36 ± 0.01 <sup>e</sup>  |
| 250 ppm           | 100 ± 0.42 <sup>a</sup> | 101 ± 1.68 <sup>a</sup> | 161 ± 0.59 <sup>bc</sup> | 242 ± 3.78 <sup>d</sup>  | 24200       | 2.4 ± 0.03 <sup>d</sup>   | 0.40 ± 0.01 <sup>ab</sup> |
| 500 ppm           | 100 ± 0.99 <sup>a</sup> | 105 ± 1.37 <sup>a</sup> | 172 ± 0.18 <sup>a</sup>  | 275 ± 1.72 <sup>a</sup>  | 27500       | 2.8 ± 0.05 <sup>a</sup>   | 0.41 ± 0.00 <sup>a</sup>  |
| 1000 ppm          | 100 ± 0.94 <sup>a</sup> | 105 ± 2.47 <sup>a</sup> | 164 ± 3.50 <sup>b</sup>  | 269 ± 5.60 <sup>ab</sup> | 26900       | 2.6 ± 0.03 <sup>bc</sup>  | 0.38 ± 0.01 <sup>cd</sup> |
| 2000 ppm          | 100 ± 1.87 <sup>a</sup> | 105 ± 2.43 <sup>a</sup> | 162 ± 3.12 <sup>bc</sup> | 262 ± 4.90 <sup>bc</sup> | 26150       | 2.5 ± 0.03 <sup>cd</sup>  | 0.37 ± 0.01 <sup>de</sup> |
| <b>SED</b>        | <b>0.108</b>            | <b>0.125</b>            | <b>0.145</b>             | <b>0.165</b>             |             | <b>0.018</b>              | <b>0.009</b>              |
| <b>CD(P=0.05)</b> | <b>0.239</b>            | <b>0.274</b>            | <b>0.305</b>             | <b>0.347</b>             |             | <b>0.039</b>              | <b>0.019</b>              |

**Table 1b.  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> nanopriming on seed germination and seedlings parameters in maize under *in vitro* laboratory condition (8<sup>th</sup> day)**

| Experiments       | Germination (%)          | Shoot length (mm)       | Root length (mm)        | Seedling length (mm)     | Vigor index | Initial fresh weight (gm) | After dry weight (gm)   |
|-------------------|--------------------------|-------------------------|-------------------------|--------------------------|-------------|---------------------------|-------------------------|
| Control           | 87 ± 1.46 <sup>e</sup>   | 131 ± 1.60 <sup>d</sup> | 174 ± 2.01 <sup>c</sup> | 305 ± 0.21 <sup>d</sup>  | 26535       | 24.2 ± 0.41 <sup>b</sup>  | 5.0 ± 0.03 <sup>b</sup> |
| 100 ppm           | 100 ± 0.97 <sup>de</sup> | 143 ± 2.14 <sup>b</sup> | 210 ± 0.71 <sup>b</sup> | 354 ± 0.24 <sup>bc</sup> | 35400       | 30.3 ± 0.98 <sup>a</sup>  | 6.3 ± 0.16 <sup>a</sup> |
| 250 ppm           | 98 ± 0.37 <sup>ab</sup>  | 151 ± 0.92 <sup>a</sup> | 211 ± 3.01 <sup>b</sup> | 362 ± 0.37 <sup>ab</sup> | 35476       | 30.7 ± 0.66 <sup>a</sup>  | 5.9 ± 0.17 <sup>a</sup> |
| 500 ppm           | 100 ± 1.12 <sup>a</sup>  | 143 ± 0.68 <sup>b</sup> | 220 ± 1.20 <sup>a</sup> | 365 ± 0.99 <sup>a</sup>  | 36500       | 32.7 ± 1.12 <sup>a</sup>  | 6.0 ± 0.14 <sup>a</sup> |
| 1000 ppm          | 96 ± 0.20 <sup>cd</sup>  | 139 ± 1.37 <sup>c</sup> | 209 ± 3.27 <sup>b</sup> | 347 ± 5.78 <sup>c</sup>  | 33312       | 27.3 ± 0.47 <sup>b</sup>  | 6.2 ± 0.11 <sup>a</sup> |
| 2000 ppm          | 94 ± 1.40 <sup>bc</sup>  | 130 ± 0.22 <sup>d</sup> | 223 ± 2.50 <sup>a</sup> | 351 ± 4.42 <sup>c</sup>  | 32994       | 26.1 ± 1.08 <sup>b</sup>  | 5.0 ± 0.07 <sup>b</sup> |
| <b>SED</b>        | <b>0.089</b>             | <b>0.079</b>            | <b>0.1136</b>           | <b>0.114</b>             |             | <b>0.2884</b>             | <b>0.1553</b>           |
| <b>CD(P=0.05)</b> | <b>0.195</b>             | <b>0.166</b>            | <b>0.2387</b>           | <b>0.2385</b>            |             | <b>0.6284</b>             | <b>0.3384</b>           |

**Table 2a. ZnO nanopriming on seed germination and seedlings parameters in rice under *in vitro* laboratory condition (14<sup>th</sup> day)**

| Experiments       | Germination (%)         | Shoot length (mm)        | Root length (mm)        | Seedling length (mm)    | Vigor index | Initial fresh weight (gm) | After dry weight (gm)    |
|-------------------|-------------------------|--------------------------|-------------------------|-------------------------|-------------|---------------------------|--------------------------|
| Control           | 89 ± 1.42 <sup>c</sup>  | 79.5 ± 1.79 <sup>d</sup> | 137 ± 1.93 <sup>b</sup> | 216 ± 0.55 <sup>b</sup> | 19224       | 3.2 ± 0.04 <sup>a</sup>   | 0.47 ± 0.00 <sup>a</sup> |
| 100 ppm           | 96 ± 0.95 <sup>b</sup>  | 87 ± 1.54 <sup>c</sup>   | 133 ± 3.05 <sup>a</sup> | 220 ± 1.72 <sup>a</sup> | 21120       | 2.1 ± 0.03 <sup>a</sup>   | 0.33 ± 0.00 <sup>b</sup> |
| 250 ppm           | 96 ± 1.87 <sup>b</sup>  | 101 ± 2.21 <sup>b</sup>  | 170 ± 0.62 <sup>c</sup> | 271 ± 5.08 <sup>c</sup> | 26016       | 2.3 ± 0.02 <sup>b</sup>   | 0.36 ± 0.01 <sup>b</sup> |
| 500 ppm           | 98 ± 1.28 <sup>ab</sup> | 105 ± 2.51 <sup>ab</sup> | 172 ± 3.67 <sup>c</sup> | 277 ± 4.18 <sup>c</sup> | 27146       | 2.1 ± 0.00 <sup>b</sup>   | 0.35 ± 0.00 <sup>b</sup> |
| 1000 ppm          | 100 ± 1.20 <sup>a</sup> | 109 ± 1.82 <sup>a</sup>  | 215 ± 2.46 <sup>c</sup> | 324 ± 2.70 <sup>d</sup> | 32400       | 2.4 ± 0.04 <sup>b</sup>   | 0.42 ± 0.01 <sup>b</sup> |
| 2000 ppm          | 100 ± 0.58 <sup>a</sup> | 107 ± 1.28 <sup>a</sup>  | 199 ± 2.90 <sup>c</sup> | 306 ± 3.98 <sup>d</sup> | 30600       | 2.2 ± 0.04 <sup>b</sup>   | 0.37 ± 0.01 <sup>a</sup> |
| <b>SED</b>        | <b>0.089</b>            | <b>0.125</b>             | <b>0.131</b>            | <b>0.226</b>            |             | <b>0.011</b>              | <b>0.007</b>             |
| <b>CD(P=0.05)</b> | <b>0.195</b>            | <b>0.276</b>             | <b>0.276</b>            | <b>0.475</b>            |             | <b>0.024</b>              | <b>0.015</b>             |

**Table 2b. ZnO nanopriming on seed germination and seedlings parameters in maize under *in vitro* laboratory condition (8<sup>th</sup> day)**

| Experiments       | Germination (%)           | Shoot length (mm)       | Root length (mm)        | Seedling length (mm)    | Vigor index | Initial fresh weight (gm) | After dry weight (gm)    |
|-------------------|---------------------------|-------------------------|-------------------------|-------------------------|-------------|---------------------------|--------------------------|
| Control           | 87.0 ± 70.38 <sup>d</sup> | 2.5 ± 0.01 <sup>f</sup> | 152 ± 2.23 <sup>d</sup> | 247 ± 3.28 <sup>e</sup> | 21489       | 17.9 ± 0.06 <sup>a</sup>  | 4.40 ± 0.18 <sup>a</sup> |
| 100 ppm           | 92.0 ± 0.63 <sup>a</sup>  | 3.3 ± 0.02 <sup>b</sup> | 209 ± 1.78 <sup>a</sup> | 338 ± 1.49 <sup>b</sup> | 31096       | 11.4 ± 0.01 <sup>c</sup>  | 3.91 ± 0.01 <sup>b</sup> |
| 250 ppm           | 92.0 ± 0.10 <sup>f</sup>  | 3.1 ± 0.01 <sup>c</sup> | 223 ± 1.90 <sup>f</sup> | 348 ± 2.01 <sup>a</sup> | 32016       | 12.5 ± 0.15 <sup>b</sup>  | 3.67 ± 0.15 <sup>b</sup> |
| 500 ppm           | 94.0 ± 0.57 <sup>c</sup>  | 3.0 ± 0.01 <sup>d</sup> | 193 ± 3.22 <sup>e</sup> | 301 ± 2.76 <sup>d</sup> | 28294       | 8.34 ± 0.23 <sup>c</sup>  | 3.06 ± 0.02 <sup>c</sup> |
| 1000 ppm          | 100.0 ± 0.55 <sup>c</sup> | 2.8 ± 0.04 <sup>e</sup> | 193 ± 1.44 <sup>c</sup> | 314 ± 0.96 <sup>c</sup> | 31400       | 17.1 ± 0.40 <sup>a</sup>  | 4.77 ± 0.20 <sup>a</sup> |
| 2000 ppm          | 99.0 ± 0.85 <sup>b</sup>  | 3.4 ± 0.05 <sup>a</sup> | 200 ± 2.30 <sup>b</sup> | 340 ± 4.40 <sup>b</sup> | 33660       | 14.0 ± 0.11 <sup>b</sup>  | 4.21 ± 0.08 <sup>a</sup> |
| <b>SED</b>        | <b>0.089</b>              | <b>0.01</b>             | <b>0.11</b>             | <b>0.01</b>             |             | <b>0.2505</b>             | <b>0.1130</b>            |
| <b>CD(P=0.05)</b> | <b>0.195</b>              | <b>0.02</b>             | <b>0.24</b>             | <b>0.23</b>             |             | <b>0.5458</b>             | <b>0.2462</b>            |

**Table 3a. Effect of foliar spray of  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> and ZnO nanoparticles on rice field micro plot and their yield attributes**

| Treatments         | Total grain weight g/m <sup>2</sup>      |                           | 1000 grain weight (gm)                   |                           | Seed length (mm)                         |                          | Seed thickness (mm)                      |                           | Seed width (mm)                          |                          | Yield (kg ha <sup>-1</sup> )             |      |
|--------------------|------------------------------------------|---------------------------|------------------------------------------|---------------------------|------------------------------------------|--------------------------|------------------------------------------|---------------------------|------------------------------------------|--------------------------|------------------------------------------|------|
|                    | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                       | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                       | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                      | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                       | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                      | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO  |
| Control            | 635 ± 12.08 <sup>c</sup>                 | 635 ± 16.20 <sup>c</sup>  | 15.4 ± 0.16 <sup>c</sup>                 | 15.6 ± 0.42 <sup>d</sup>  | 7.5 ± 0.15 <sup>b</sup>                  | 7.9 ± 0.09 <sup>d</sup>  | 1.56 ± 0.00 <sup>b</sup>                 | 1.65 ± 0.01 <sup>c</sup>  | 3.16 ± 0.08 <sup>c</sup>                 | 3.15 ± 0.02 <sup>c</sup> | 6350                                     | 6350 |
| 100 ppm            | 643 ± 27.24 <sup>c</sup>                 | 630 ± 0.0 <sup>c</sup>    | 15.8 ± 0.39 <sup>bc</sup>                | 16.0 ± 0.29 <sup>cd</sup> | 7.7 ± 0.12 <sup>b</sup>                  | 8.2 ± 0.19 <sup>c</sup>  | 1.69 ± 0.04 <sup>a</sup>                 | 1.71 ± 0.04 <sup>bc</sup> | 3.35 ± 0.07 <sup>b</sup>                 | 3.55 ± 0.04 <sup>b</sup> | 6430                                     | 6300 |
| 250 ppm            | 650 ± 20.51 <sup>c</sup>                 | 646 ± 27.20 <sup>c</sup>  | 16.3 ± 0.12 <sup>b</sup>                 | 16.5 ± 0.40 <sup>bc</sup> | 8.2 ± 0.12 <sup>a</sup>                  | 8.4 ± 0.14 <sup>bc</sup> | 1.71 ± 0.01 <sup>a</sup>                 | 1.78 ± 0.01 <sup>ab</sup> | 3.46 ± 0.01 <sup>b</sup>                 | 3.72 ± 0.03 <sup>a</sup> | 6500                                     | 6460 |
| 500 ppm            | 675 ± 20.08 <sup>b</sup>                 | 655 ± 26.65 <sup>bc</sup> | 17.3 ± 0.42 <sup>a</sup>                 | 17.4 ± 0.09 <sup>a</sup>  | 8.3 ± 0.10 <sup>a</sup>                  | 8.7 ± 0.12 <sup>a</sup>  | 1.72 ± 0.03 <sup>a</sup>                 | 1.81 ± 0.04 <sup>a</sup>  | 3.77 ± 0.08 <sup>a</sup>                 | 3.81 ± 0.08 <sup>a</sup> | 6750                                     | 6550 |
| 1000 ppm           | 695 ± 30.70 <sup>b</sup>                 | 680 ± 29.59 <sup>ab</sup> | 17.3 ± 0.04 <sup>a</sup>                 | 17.3 ± 0.37 <sup>ab</sup> | 8.3 ± 0.10 <sup>a</sup>                  | 8.6 ± 0.06 <sup>ab</sup> | 1.71 ± 0.00 <sup>a</sup>                 | 1.80 ± 0.04 <sup>a</sup>  | 3.76 ± 0.07 <sup>a</sup>                 | 3.80 ± 0.07 <sup>a</sup> | 6950                                     | 6800 |
| 2000 ppm           | 723 ± 27.37 <sup>a</sup>                 | 696 ± 23.18 <sup>a</sup>  | 17.3 ± 0.07 <sup>a</sup>                 | 17.4 ± 0.00 <sup>a</sup>  | 8.3 ± 0.06 <sup>a</sup>                  | 8.6 ± 0.15 <sup>ab</sup> | 1.72 ± 0.00 <sup>a</sup>                 | 1.81 ± 0.02 <sup>a</sup>  | 3.75 ± 0.08 <sup>a</sup>                 | 3.81 ± 0.03 <sup>a</sup> | 7230                                     | 6960 |
| <b>SED</b>         | <b>0.006</b>                             | <b>0.009</b>              | <b>0.035</b>                             | <b>0.048</b>              | <b>0.022</b>                             | <b>0.020</b>             | <b>0.016</b>                             | <b>0.015</b>              | <b>0.020</b>                             | <b>0.017</b>             | <b>-</b>                                 |      |
| <b>CD (P=0.05)</b> | <b>0.015</b>                             | <b>0.020</b>              | <b>0.078</b>                             | <b>0.106</b>              | <b>0.049</b>                             | <b>0.048</b>             | <b>0.035</b>                             | <b>0.031</b>              | <b>0.041</b>                             | <b>0.036</b>             | <b>-</b>                                 |      |

**Table 3b. Effect of foliar spray of  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> and ZnO nanoparticles on maize field micro plot and their yield attributes**

| Treatments         | Total grain weight g/m <sup>2</sup>      |                           | 1000 grain weight (gm)                   |                         | Seed length (mm)                         |                          | Seed thickness (mm)                      |                         | Seed width (mm)                          |                         | Yield (kg ha <sup>-1</sup> )             |      |
|--------------------|------------------------------------------|---------------------------|------------------------------------------|-------------------------|------------------------------------------|--------------------------|------------------------------------------|-------------------------|------------------------------------------|-------------------------|------------------------------------------|------|
|                    | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                       | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                     | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                      | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                     | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO                     | $\gamma$ -Fe <sub>2</sub> O <sub>3</sub> | ZnO  |
| Control            | 51.00 ± 0.17 <sup>c</sup>                | 51.00 ± 1.05 <sup>d</sup> | 310 ± 5.52 <sup>c</sup>                  | 214 ± 0.69 <sup>d</sup> | 10.4 ± 0.15 <sup>c</sup>                 | 9.8 ± 0.11 <sup>b</sup>  | 5 ± 0.08 <sup>b</sup>                    | 5 ± 0.08 <sup>c</sup>   | 8.2 ± 0.15 <sup>bc</sup>                 | 8 ± 0.04 <sup>c</sup>   | 5100                                     | 5100 |
| 100 ppm            | 55.80 ± 2.06 <sup>d</sup>                | 53.10 ± 0.91 <sup>d</sup> | 326 ± 8.14 <sup>b</sup>                  | 269 ± 2.24 <sup>a</sup> | 11 ± 0.03 <sup>b</sup>                   | 10 ± 0.02 <sup>b</sup>   | 5 ± 0.10 <sup>b</sup>                    | 5 ± 0.10 <sup>b</sup>   | 8.5 ± 0.21 <sup>ab</sup>                 | 8.1 ± 0.16 <sup>b</sup> | 5580                                     | 5310 |
| 250 ppm            | 61.60 ± 1.17 <sup>c</sup>                | 58.90 ± 0.64 <sup>c</sup> | 340 ± 4.95 <sup>a</sup>                  | 251 ± 0.00 <sup>b</sup> | 11.3 ± 0.01 <sup>a</sup>                 | 10.8 ± 0.16 <sup>a</sup> | 5 ± 0.01 <sup>c</sup>                    | 5 ± 0.01 <sup>bc</sup>  | 8.7 ± 0.17 <sup>ab</sup>                 | 8.1 ± 0.12 <sup>b</sup> | 6160                                     | 5890 |
| 500 ppm            | 63.13 ± 2.62 <sup>bc</sup>               | 62.15 ± 1.18 <sup>b</sup> | 345 ± 0.54 <sup>ab</sup>                 | 240 ± 3.50 <sup>c</sup> | 11.1 ± 0.11 <sup>c</sup>                 | 10.6 ± 0.22 <sup>a</sup> | 5.1 ± 0.05 <sup>a</sup>                  | 5.1 ± 0.05 <sup>a</sup> | 8.7 ± 0.20 <sup>ab</sup>                 | 8 ± 0.08 <sup>bc</sup>  | 6313                                     | 6215 |
| 1000 ppm           | 65.80 ± 0.47 <sup>b</sup>                | 63.55 ± 0.52 <sup>b</sup> | 351 ± 0.91 <sup>a</sup>                  | 272 ± 0.99 <sup>a</sup> | 11.2 ± 0.19 <sup>d</sup>                 | 11 ± 0.26 <sup>a</sup>   | 5.1 ± 0.10 <sup>a</sup>                  | 5 ± 0.10 <sup>b</sup>   | 8.8 ± 0.19 <sup>a</sup>                  | 8.3 ± 0.09 <sup>a</sup> | 6580                                     | 6355 |
| 2000 ppm           | 72.05 ± 2.92 <sup>a</sup>                | 69.10 ± 3.05 <sup>a</sup> | 353 ± 0.92 <sup>a</sup>                  | 273 ± 3.27 <sup>a</sup> | 11 ± 0.14 <sup>c</sup>                   | 10.9 ± 0.16 <sup>a</sup> | 5 ± 0.05 <sup>bc</sup>                   | 5.1 ± 0.05 <sup>a</sup> | 8.0 ± 0.02 <sup>c</sup>                  | 8.1 ± 0.17 <sup>b</sup> | 7205                                     | 6910 |
| <b>SED</b>         | <b>0.012</b>                             | <b>0.009</b>              | <b>0.183</b>                             | <b>0.200</b>            | <b>0.037</b>                             | <b>0.414</b>             | <b>0.022</b>                             | <b>0.020</b>            | <b>0.038</b>                             | <b>0.036</b>            | <b>-</b>                                 |      |
| <b>CD (P=0.05)</b> | <b>0.023</b>                             | <b>0.018</b>              | <b>0.403</b>                             | <b>0.441</b>            | <b>0.082</b>                             | <b>0.087</b>             | <b>0.049</b>                             | <b>0.042</b>            | <b>0.084</b>                             | <b>0.083</b>            | <b>-</b>                                 |      |