Supplementary Material

**Supplementary Table 1.** The values ofherbicide residues in water and soil used in this study.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Herbicide | Country | Year | Herbicide residues  | Average values of herbicide residues  | References |
| *In water (mg/L)* |
| Glyphosate | Argentina | 2008 | 0.1000, 0.7000 | 0.1655 | Peruzzo et al., 2008 |
| Brazil | 2014 | 0.2300, 0.2900, 0.3300 | Delmonoco et al., 2014 |
| Denmark and Greenland | 1999-2003 | 0.0001 | Kjaer et al., 2004 |
| Hungary | 2013 | 0.0010 | Mörtl et al., 2013 |
| Mexico | 2017 | 0.0014, 0.0013, 0.0013 | Osten and Dzul-Caamal, 2017 |
| 2,4-D | Australia | 2005 | 0.0002, 0.0004, 0.0006, 0.0016, 0.0019 | 0.079 | Mitchell et al., 2005 |
| Malaysia | 2007 | 0.0000084, 0.954, 0.070 | Fisher et al, 2013 |
| Malaysia | 2011 | 0.00004, 0.0149 | Ismail et al., 2011 |
| Maxico | 2013 | 0.000005 | Félix–Cañedo et al., 2013 |
| Spain | 2007 | 0.0001 | Kuster et al., 2007 |
| *In soil (mg/kg soil)* |
| Glyphosate | Argentina | 2008 | 0.500, 5.000 | 0.165 | Peruzzo et al., 2008 |
| China | 2015 | 0.130, 0.910, 0.100, 0.140, 0.100, 0.990 | Paipard, et al. 2014 |
| European countries | 2018 | 0.020, 2.000 | Silva, et al. 2018 |
| Finland | 2007 | 0.016 | Laitinen, et al. 2007 |
| Thailand | 2014 | 9.900 | Zhang, et al., 2015 |
| 2,4-D | Brazil | 2017 | 0.000 | 0.153 | Baumgartner et al., 2005 |
| India | 2005 | 0.009, 0.016 | Kashyap et al., 2005 |
| Malaysia | 2011 | 0.046, 0.128 | Ismail et al., 2011 |
| Nigeria | 2012 | 0.013, 0.180 | Gushit et al., 2012 |
| Russia | 2016 | 1.100 | Zhichkina et al., 2020 |
| USA | 2008 | 0.0133, 0.030 | Morgan et al., 2008 |

**Supplementary Table 2.** Preliminary test for minimum inhibitory concentration(MIC) of herbicides on the growth of rice seedling.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | Shoot Length (cm) | Root Length (cm) | Fresh weight(g) | Dry weight(g) | SVI |
| Control | 1.43±0.08 c | 2.99±0.35 a | 0.2001±0.0168 abc | 0.0387±0.0186 ab | 377.00±53.74 a |
| G 0.1 mg/L | 1.75±0.03 a | 2.52±0.21 b | 0.2583±0.0134 a | 0.0344±0.0023 ab | 388.50±27.578 a |
| G 0.5 mg/L | 1.50±0.02 abc | 1.21±0.01 c | 0.1908±0.0178 abc | 0.0279±0.0013 abc | **243.90±1.27\* c** |
| G 1 mg/L | 1.58±0.08 abc | 1.13±0.19 c | 0.1531±0.0500 c | 0.0227±0.0012 bc | 230.05±5.59 cd |
| G 10 mg/L | 0.92±0.04 d | 0.77±0.01 c | 0.1416±0.0117 c | 0.0230±0.0006 bc | 169.00±5.66 de |
| D 0.1 mg/L | 1.80±0.33 ab | 1.06±0.29 c | 0.2310±0.0340 ab | 0.0465±0.0064 a | **308.00±31.11\* b** |
| D 0.5 mg/L | 1.59±0.09 abc | 0.81±0.06 c | 0.2305±0.0276 ab | 0.0325±0.0021 ab | 223.50±38.89 cd |
| D 1 mg/L | 1.68±0.04 abc | 1.01±0.14 c | 0.2455±0.0446 a | 0.0355±0.0106 ab | 277.50±2.12 bc |
| D 10 mg/L | 1.47±0.00 bc | 0.00±0.00 d | 0.1585±0.0262 bc | 0.0125±0.0007 c | 140.15±11.10 e |

G = Glyphosate, D = 2,4-D, SVI = Seedling Vigor Index

\*0.5 mg/L of glyphosate and 0.1 mg/L of 2,4-D were selected as the minimum inhibitory concentration (MIC) of herbicides on the growth of rice seedling according to their significant lower SVI compared with the control.

**Supplementary Table 3.** Experimental treatments for the determination of effects of herbicides and *Nostoc* sp. N1 on the germination of rice seedlings.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatment | *Nostoc* cells (g/L) | Glyphosate herbicide(mg/L) | Treatment | *Nostoc* cells (g/L) | 2,4-D herbicide(mg/L) |
| 5.0 | 10.0 | 0.5 | 1.0 | 2.5 | 5.0 | 5.0 | 10.0 | 0.01 | 0.1 | 1.0 | 5.0 |
| *Glyphosate experiment* | *2,4-D experiment* |
| Control | **-** | **-** | **-** | **-** | **-** | **-** | Control | **-** | **-** | **-** | **-** | **-** | **-** |
| T1 | **/** | **-** | **-** | **-** | **-** | **-** | T1 | **/** | **-** | **-** | **-** | **-** | **-** |
| T2 | **-** | **/** | **-** | **-** | **-** | **-** | T2 | **-** | **/** | **-** | **-** | **-** | **-** |
| T3 | **-** | **-** | **/** | **-** | **-** | **-** | T3 | **-** | **-** | **/** | **-** | **-** | **-** |
| T4 | **-** | **-** | **-** | **/** | **-** | **-** | T4 | **-** | **-** | **-** | **/** | **-** | **-** |
| T5 | **-** | **-** | **-** | **-** | **/** | **-** | T5 | **-** | **-** | **-** | **-** | **/** | **-** |
| T6 | **-** | **-** | **-** | **-** | **-** | **/** | T6 | **-** | **-** | **-** | **-** | **-** | **/** |
| T7 | **/** | **-** | **/** | **-** | **-** | **-** | T7 | **/** | **-** | **/** | **-** | **-** | **-** |
| T8 | **/** | **-** | **-** | **/** | **-** | **-** | T8 | **/** | **-** | **-** | **/** | **-** | **-** |
| T9 | **/** | **-** | **-** | **-** | **/** | **-** | T9 | **/** | **-** | **-** | **-** | **/** | **-** |
| T10 | **/** | **-** | **-** | **-** | **-** | **/** | T10 | **/** | **-** | **-** | **-** | **-** | **/** |
| T11 | **-** | **/** | **/** | **-** | **-** | **-** | T11 | **-** | **/** | **/** | **-** | **-** | **-** |
| T12 | **-** | **/** | **-** | **/** | **-** | **-** | T12 | **-** | **/** | **-** | **/** | **-** | **-** |
| T13 | **-** | **/** | **-** | **-** | **/** | **-** | T13 | **-** | **/** | **-** | **-** | **/** | **-** |
| T14 | **-** | **/** | **-** | **-** | **-** | **/** | T14 | **-** | **/** | **-** | **-** | **-** | **/** |

**Supplementary Table 4.** Calculation of phytotoxicity index (PI).

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatment | SL | RL | FW | DW | PI\* | Treatment | SL | RL | FW | DW | PI |
| Control | 0 | 0 | 0 | 0 | 0.00 | Control | 0 | 0 | 0 | 0 | 0.00 |
| N 5.0 g/L | -2 | -2 | -1 | -1 | -1.5 | N 5.0 g/L | -1 | -1 | -1 | -2 | -1.25 |
| N 10.0 g/L | -2 | -2 | -1 | -1 | -1.5 | N 10.0 g/L | -1 | -3 | -1 | -3 | -2.00 |
| G 0.5 mg/L | -1 | 1 | 1 | 1 | 0.50 | D 0.01 mg/L | -1 | -2 | 1 | -2 | -1.00 |
| G 1.0 mg/L | 1 | 2 | 1 | 1 | 1.25 | D 0.1 mg/L | -1 | 3 | -1 | -2 | -0.25 |
| G 2.5 mg/L | 3 | 3 | 2 | 2 | 2.50 | D 1.0 mg/L | -1 | 3 | -1 | -2 | -0.25 |
| G 5.0 mg/L | 3 | 4 | 2 | 2 | 2.75 | D 5.0 mg/L | 2 | 4 | 2 | 1 | 2.25 |
| N 5.0+G 0.5 | -2 | -1 | -1 | -1 | -1.25 | N 5.0+D 0.01 | -1 | -1 | -1 | -2 | -1.25 |
| N 5.0+G 1.0 | -1 | 1 | -1 | -1 | 0.50 | N 5.0+ D 0.1 | -1 | 2 | 1 | -1 | 0.25 |
| N 5.0+ G2.5 | 1 | 3 | 1 | 1 | 1.50 | N 5.0+ D 1.0 | 1 | 1 | 1 | -2 | 0.25 |
| N 5.0+ G 5.0 | 3 | 4 | 2 | 2 | 2.75 | N 5.0+ D 5.0 | 2 | 4 | 2 | 1 | 2.25 |
| N 10.0+ G 0.5 | -1 | 1 | -1 | -1 | 0.50 | N 10.0+D 0.01 | -1 | -1 | 1 | -2 | -0.75 |
| N 10.0+ G 1.0 | -1 | 1 | -1 | -1 |  0.50 | N 10.0+ D 0.1 | -1 | 2 | -1 | -2 | -0.50 |
| N 10.0+ G 2.5 | 1 | 2 | 1 | 1 | 1.25 | N 10.0+ D 1.0 | 1 | 2 | -1 | -2 | 0.00 |
| N 10.0+ G 5.0 | 3 | 3 | 2 | 2 | 2.50 | N 10.0+ D 5.0 | 2 | 4 | 2 | 1 | 2.25 |

N = *Nostoc* sp. N1; G = Glyphosate herbicide; SL = Shoot length; RL = Root length; FW = Fresh weight; DW = Dry weight

\*Phytotoxicity index were classified according to the reduction (%) in different growth parameters, i.e., shoot length, root length, fresh weight and dry weight due to herbicide toxicity or improvement (%) in different parameters due to *Nostoc* sp. N1 cells addition. Different levels classified are level 1 (0–25%), level (26–50%), level 3 (51–75%), level 4 (>75%) and correspondingly negative values were classified for increase (%) in growth of rice.

**Supplementary Table 5.** Effects of glyphosate herbicide and *Nostoc* sp. N1 cells on the germination and growth parameters of 7-day-old rice seedlings

|  |  |
| --- | --- |
| Treatment |  growth parameters |
| Shoot length(cm) | Root length(cm) | Fresh weight(g) | Dry weight(g) |
| Control | 3.38±0.08 de | 4.08±0.23 cd | 0.30±0.02 abc | 0.0435±0.0013 cde |
| N 5 g/L | 4.24±0.18 ab | 5.15±0.29 ab | 0.35±0.03 ab | 0.0528±0.0036 ab |
| N 10 g/L | 4.66±0.43 a | 5.49±1.19 a | 0.36±0.05 a | 0.0572±0.0053 a |
| G 0.5 mg/L | 3.44±0.24 cde | 3.25±0.44 e | 0.28±0.02 c | 0.0407±0.0042 de |
| G 1 mg/L | 3.23±0.18 e | 2.41±0.26 f | 0.27±0.03 cd | 0.0388±0.0056 e |
| G 2.5 mg/L | 1.60±0.40 g | 1.42±0.31 gh | 0.22±0.01 de | 0.0304±0.0021 fg |
| G 5 mg/L | 0.89±0.10 i | 0.67±0.07 h | 0.17±0.03 e | 0.0243±0.0031 g |
| N 5+ G 0.5 | 4.39±0.04 a | 4.68±0.19 bc | 0.35±0.07 ab | 0.0502±0.0051 abc |
| N 5+G 1 | 3.89±0.56 bc | 3.39±0.44 de | 0.33±0.03 abc | 0.0471±0.0052 bcd |
| N 5+G 2.5 | 2.59±0.12 f | 1.69±0.28 fg | 0.29±0.03 bc | 0.0372±0.0052 ef |
| N 5+G 5 | 0.98±0.15 hi | 0.94±0.10 gh | 0.20±0.04 e | 0.0284±0.0030 g |
| N 10+G 0.5 | 3.76±0.36 cd | 4.06±0.60 cd | 0.31±0.03 abc | 0.0441±0.0021 cde |
| N 10+G 1 | 3.58±0.07 cde | 3.33±0.39 de | 0.31±0.03 abc | 0.0401±0.0079 de |
| N 10+G 2.5 | 2.57±0.21 f | 2.17±0.04 f | 0.27±0.01 cd | 0.0382±0.0013 e |
| N 10+G 5 | 1.35±0.02 gh | 0.88±0.01 h | 0.21±0.02 de | 0.0296±0.0011 g |

N = *Nostoc* sp. N1; G = Glyphosate herbicide

a–i Means followed by the same letter are not significantly different at *P* = 0.05

**Supplementary Table 6.** Effects of 2,4-D herbicide and *Nostoc* sp. N1 cells on the germination and growth parameters of 7-day-old rice seedlings

|  |  |
| --- | --- |
| Treatment | Germination and growth parameters |
| Shoot length(cm) | Root length(cm) | Fresh weight(g) | Dry weight(g) |
| Control | 3.45±0.24 a | 2.76±1.19 bc | 0.28±0.01 ab | 0.0472±0.0019 bc |
| N 5 g/L | 3.61±0.34 a | 3.25±1.20 ab | 0.30±0.02 ab | 0.0512±0.0010 ab |
| N 10 g/L | 3.74±0.28 a | 4.16±0.20 a | 0.30±0.02 ab | 0.0575±0.0051 a |
| D 0.01 mg/L | 3.64±0.48 a | 4.03±0.29 a | 0.26±0.02 b | 0.0451±0.0071 bc |
| D 0.1 mg/L | 3.72±0.13 a | 1.29±0.22 de | 0.31±0.01 ab | 0.0526±0.0079 ab |
| D 1 mg/L | 3.48±0.36 a | 1.32±0.17 de | 0.29±0.03 ab | 0.0487±0.0072 bc |
| D 5 mg/L | 2.47±0.18 bc | 0.00±0.00 f | 0.18±0.02 c | 0.0233±0.0020 d |
| N 5+D 0.01 | 3.78±0.14 a | 3.27±0.63 ab | 0.31±0.02 ab | 0.0505±0.0039 abc |
| N 5+D 0.1 | 3.70±1.27 a | 1.69±0.29 cd | 0.27±0.03 ab | 0.0420±0.0014 c |
| N 5+D 1 | 3.10±0.84 ab | 2.11±1.37 cd | 0.27±0.03 ab | 0.0471±0.0014 bc |
| N 5+D 5 | 2.12±0.08 c | 0.23±0.05 ef | 0.17±0.01 c | 0.0230±0.0017 d |
| N 10+D 0.01 | 3.58±0.18 a | 3.35±0.38 ab | 0.27±0.04 ab | 0.0485±0.0021 ab |
| N 10+D 0.1 | 3.82±0.33 a | 1.93±0.07 cd | 0.33±0.02 a | 0.0527±0.0006 bc |
| N 10+D 1 | 3.30±0.49 a | 1.79±0.20 cd | 0.30±0.05 ab | 0.0462±0.0049 bc |
| N 10+D 5 | 2.30±0.05 bc | 0.32±0.14 ef | 0.19±0.01 c | 0.0247±0.0029 d |

N = *Nostoc* sp. N1; D = 2,4-D herbicide

 a–f Means followed by the same letter are not significantly different at *P* = 0.05

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(C)

(B)

(A)

**Supplementary Figure 1.** Morphological study of *Nostoc* sp. cells. (A) *Nostoc* colonies enveloped by mucilage. (B) Vegetative cells of *Nostoc* sp. cultivated under N-free BG11 media (the arrow indicate heterocyst). (C) Nigrosin staining showing the production of large amounts of mucus covering the *Nostoc* sp. cells.

**Supplementary** **Figure 2.** Growth curve of *Nostoc* sp. N1.

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