**Supplementary material**

Table S1. Difference of temperature (°C) reached between the center and the periphery of the soil heated using different power × duration combination of microwave; desired temperature (90°C) is indicated in bold.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Power (kW) | | |
| Duration (minutes) | 2 | 4 | 6 |
| 2 | +5 | +8 | **+10** |
| 4 | +10 | **+6** | **equal** |
| 8 | **+10** |  |  |

Table S2. Difference of temperature (°C) reached between the center and the periphery of the soil heated using different power × duration combination of microwave and moisture of soil; desired temperature (90°C) is indicated in bold.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Moisture | H1 | |  | H2 | |  | H3 | |
|  | Power (kW) | 2 | 4 |  | 2 | 4 |  | 2 | 4 |
| Duration (minutes) | 2 |  | +9 |  |  | +11 |  |  | +3 |
|  | 4 | **+10** | **equal** |  | +20 | **equal** |  | +3 | +1 |
|  | 8 | **equal** |  |  | **equal** |  |  | **+16** |  |

**Additional Germination Parameters**

Germination capacity is usually assessed by germination percentage. However, we also considered three other parameters to assess the colonization ability, which it is important to take into account for ecosystem management purposes (Mesléard *et al*. 2016).

* the first day of germination,
* the mean time of germination (Brenchley & Probert, 1998) = (Ʃ*ni* × *di*)*/N*, where *n* is the number of germinated seeds at day *i*, *d* is the incubation period (days), and *N* is the total number of germinations at day *i*,
* the speed of germination (Chiapusio *et al.* 1997): *v* = (Ʃ (*Nn* – *Nn-1*) × 1/n) × 100, where *N* is the proportion of germination obtained after *n* days.

These parameters were considered only for *Experiment 1*, because the analysis of other metrics is meaningless due to the wide disparity in the germination percentage between species and different treatment modalities for *Experiment 2* (see results).

For treatments for which there was a significant germination percentage, Poisson regression was performed to test their effect on the first day of germination (count data) and gamma regression was performed to test their effect on the mean time and speed of germination (non-normal continuous positive data).

**Results**

First day of germination, mean time and speed of germination were all significantly affected by the microwave treatment × depth × species interaction

For *S. gigantea*, 2kW4min treatment increased the number of days before the first germination of seeds located at a 12 cm depth only, and 4kW2min treatment increased the number of days before the first germination for seeds located at a 2 cm depth only, compared to control treatment (Table S3, Fig S1).

In the control treatment, *D. stramonium* showed a higher mean time of germination and lower speed of germination than *S. gigantea* and *F. × bohemica*. For *D. stramonium*, the 2kW4min treatment slightly increased the mean time of germination and slightly reduced the speed of germination of seeds located at a 12 cm depth only (Table S3, Fig S1). For *S. gigantea*, 2kW4min increased the mean time of germination and reduced the speed of germination of seeds located at a 12 cm depth only, and the 4kW2min treatment increased the mean time of germination and reduced the speed of germination for seeds located at a 2 cm depth only (Table S3, Fig S1).

Table S3. Results of Generalized Linear Models testing the effect of microwave treatment, depth and species and their interactions on first day of germination (Poisson regression), mean time and speed of germination (gamma regression).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | First day of germination | Mean time of germination | Speed of germination |
| Microwave treatment | *df* | 3 | 3 | 3 |
| Wald statistic (χ2) | 16.58 | 0.66 | 0.60 |
| *P* | **< 0.001** | 0.080 | **0.013** |
| Depth | *df* | 1 | 1 | 1 |
| Wald statistic (χ2) | 0.07 | 0.08 | 0.007 |
| *P* | 0.796 | 0.350 | 0.721 |
| Species | *df* | 2 | 2 | 2 |
| Wald statistic (χ2) | 6.63 | 15.92 | 4.19 |
| *P* | **0.036** | **< 0.001** | **< 0.001** |
| Microwave treatment × Depth | *df* | 3 | 3 | 3 |
| Wald statistic (χ2) | 10.62 | 1.22 | 0.19 |
| *P* | **0.014** | **0.006** | 0.328 |
| Microwave treatment × Species | *df* | 6 | 6 | 6 |
| Wald statistic (χ2) | 12.49 | 4.36 | 0.87 |
| *P* | 0.052 | **< 0.001** | **0.016** |
| Depth × Species | *df* | 2 | 2 | 2 |
| Wald statistic (χ2) | 0.71 | 0.06 | 0.01 |
| *P* | 0.700 | 0.725 | 0.902 |
| Microwave treatment × Depth × Species | *df* | 6 | 6 | 6 |
| Wald statistic (χ2) | 12.77 | 2.47 | 0.87 |
| *P* | **0.046** | **< 0.001** | **0.017** |

The Wald statistic used to test the significance of the parameters, degrees of freedom (*df*) and p values (*P*) are indicated. Values in bold indicate significance at *P* < 0.05.



Figure S1. First day of germination, mean time and speed of germination of *Solidago gigantea*, *Fallopia × bohemica* and *Datura stramonium* in control treatment and after different power × duration microwave treatments for which a significant germination percentage remains at two depths in the soil. Top: seed bags placed at 2 cm depth; bottom: seed bags placed at 12 cm depth. Values are expressed as means ± SE of the five replicates. Letters indicate statistically significant differences (microwave treatment × depth × species interaction, *post-hoc* Tukey’s test, *P* < 0.05).

**Discussion**

Some heating microwave treatments which did not reach temperatures allowing seed inhibition could have stimulated the germination process (Brodie *et al* 2011b; Sahin 2014). Microwave treatments can potentially delay the first day of germination, increase the mean time of germination or reduce germination speed, thus limiting the temporal window with favorable conditions for germination and survival of seedlings. Some treatments affected *S. gigantea* germination capacity, with an increase in the number of days before the first germination and in the mean time of germination, and a decrease in germination speed. Conversely, *D. stramonium*, that showed a longer mean time of germination and a lower speed of germination than the other two species in the control treatment, improved its germination capacity with one of these treatments (i.e. 2kW4min for seeds located at a 12 cm depth), with a decrease in the mean time of germination and an increase in the speed of germination. Microwave heating may have led to the opening of the hard coat of *D. stramonium* seeds and therefore a faster imbibition and/or gases exchange and subsequent germination (Hanna 1984; Kelly *et al.* 1992). These results show that some treatments should not be used because they do not completely inhibit seed germination and could for some species enhance germination capacity. These differences in response between species will depend on their optimum temperature required for germination, and seed sensitivity to the temperature increase. This requires further investigation in future work.

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