Use of Microwaves for Disinfection of Farmland: a Feasibility Study

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Motivation

• Why do we need to disinfect the soil? to favour farming

• Actual methods: pesticides (e.g. Toxaphene [1]), bioremediation (using other antagonist biological organisms, e.g. Lumbricus terrestris and Coccinellidae [2]-[3])

• Other Methods: Microwaves Power


Soil

USDA texture triangle of soils (Soil Conservation Service, 1987).
STEPS

I. Compute the dielectric constant of soil as function of temperature

II. Compute the Soil Impedance as function of space

III. Compute the Electric Field Distribution inside the soil layer

IV. Compute the MW Power Density Heating the soil

V. Compute the Temperature distribution by solving the Heat Transfer Equation with FDTD method
EM and Thermal Discretization

The problem to solve is to define the complete discretization of the EM dynamics in space and temperature, which in turn depends by temperature.

The EM dynamics is expressed by Soil Impedance, the Incident Electric Field and the Irradiated Power to the Soil. Before, we assume some boundary condition for solve the problem with FDTD Method:

- The boundary condition at $z=\infty$ is replaced by a condition at a finite $z$.
- $z>z_{\infty}$, $T=T_0 \ \forall t$
Dielectric Constant of Water (Ray, 1972)

\[ \varepsilon' = \varepsilon_\infty + \frac{(\varepsilon_s(T) - \varepsilon_\infty(T)) \left[ 1 + \left( \frac{\lambda_s(T)}{\lambda} \right)^{1-\alpha(T)} \sin \left( \frac{\alpha(T)\pi}{2} \right) \right]}{1 + 2 \left( \frac{\lambda_s(T)}{\lambda} \right)^{1-\alpha(T)} \sin \left( \frac{\alpha(T)\pi}{2} \right) + \left( \frac{\lambda_s(T)}{\lambda} \right)^{2(1-\alpha(T))}} \]

\[ \varepsilon'' = \frac{(\varepsilon_s(T) - \varepsilon_\infty(T)) \left[ 1 + \left( \frac{\lambda_s(T)}{\lambda} \right)^{1-\alpha(T)} \cos \left( \frac{\alpha(T)\pi}{2} \right) \right]}{1 + 2 \left( \frac{\lambda_s(T)}{\lambda} \right)^{1-\alpha(T)} \sin \left( \frac{\alpha(T)\pi}{2} \right) + \left( \frac{\lambda_s(T)}{\lambda} \right)^{2(1-\alpha(T))}} + \frac{\sigma\lambda}{18.8496 \times 10^{10}} \]

The EM propagation in this line is described by the telegrapher’s equations

\[
\frac{d E(z)}{d z} = -j \omega \mu_0 H(z)
\]
\[
\frac{d H(z)}{d z} = -j \omega \varepsilon[z, T(z)] E(z)
\]

An effective solution starts from the computation of \( Z(z) \) by a backward numerical integration of the complex Riccati equation:

\[
\frac{dZ}{dz} = -j \frac{\omega \mu_0}{\zeta} + j \frac{\omega \varepsilon_0}{\zeta} \varepsilon_r[z, T(z)] \frac{E^2}{H^2} = -j \beta_0 + j \beta_0 \varepsilon_r[z, T(z)] Z^2(z) = j \beta_0 \left\{ \varepsilon_r[z, T(z)] Z^2(z) - 1 \right\}
\]
\[
\frac{d E(z)}{d z} = -j \omega \mu_0 H(z) = -j \omega \mu_0 \frac{E(z)}{\zeta Z(z)}
\]

\( Z(z) = \frac{1}{\zeta} \frac{E(z)}{H(z)} \)
Heat Transfer Equation

\[ \rho C \frac{\partial T}{\partial t} = \kappa \nabla^2 T + P_T = \kappa \frac{\partial^2 T(z,t)}{\partial z^2} + P_T(z,T) \]

- \( T \): temperature [°K];
- \( \rho \): soil density [kg/m\(^3\)];
- \( C \): specific heat at constant pressure [W/m\(^3\)K];
- \( \kappa \): soil thermal conductivity [J/kg\(\cdot\)K];
- \( P_T \): Thermal Power generated during MW irradiation [W/m\(^3\)];

\[ \kappa(0,t) \left[ \frac{\partial T(0,t)}{\partial z} \right] = h_c (T(0,t) - T_A) \]

- \( T_A \) is the external air temperature.
- \( h_c \) is the heat transfer coefficient in W m\(^{-2}\)K\(^{-1}\).
FDTD SOLUTION OF HEAT TRANSFER EQUATION

\[
T_{q,n+1} = T_{q,n} + \frac{\Delta t}{\rho [q \Delta z, T_{q,n}] C[q \Delta z, T_{q,n0}]} \left[ \kappa[q \Delta z, T_{q,n}] \frac{T_{q+1,n} - 2T_{q,n} + T_{q-1,n}}{(\Delta z)^2} + P_T(q \Delta z) \right] \quad q > 0
\]

\[
T_{1,n} = T_{0,n} + \frac{h_c \Delta z}{\kappa[0,T_{0,n}]} (T_{0,n} - T_A) = \left( 1 + \frac{h_c \Delta z}{\kappa[0,T_{0,n-1} + T_A]} \right) T_{0,n} - \frac{h_c \Delta z}{\kappa[0,T_{0,n}]} T_A
\]
Survival of *Fusarium oxysporum* as a function of time at different temperatures.

Soil moisture distribution used in the tests
Soil temperature distribution for field A, for soil moisture distribution B.

RESULTS

<table>
<thead>
<tr>
<th>Fields</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand [%]</td>
<td>29</td>
</tr>
<tr>
<td>Silt [%]</td>
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</tr>
<tr>
<td>Clay [%]</td>
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</tr>
<tr>
<td>Long.</td>
<td>9.166919204°</td>
</tr>
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RESULTS

![Graph showing soil temperature distribution for field A, for soil moisture distribution A.]

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Surface temperature distribution for different power densities, for the humidity distribution shown as “profile B.”
RESULTS

Graph showing the real and imaginary parts of input impedance over time.
Conclusions

• The feasibility of using Microwaves to disinfect soil is demonstrated;
• For a given farmland soil, an optimization should be performed considering water content, MW power and thermal properties to reduce the overall disinfection time without harming useful flora and fauna;
• Possibility to include the Water Evaporation.
Thank you for your attention