Applied Electromagnetics Group

Università di Cagliari

Use of Microwaves for Disinfection of Farmland: a Feasibility Study

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Motivation

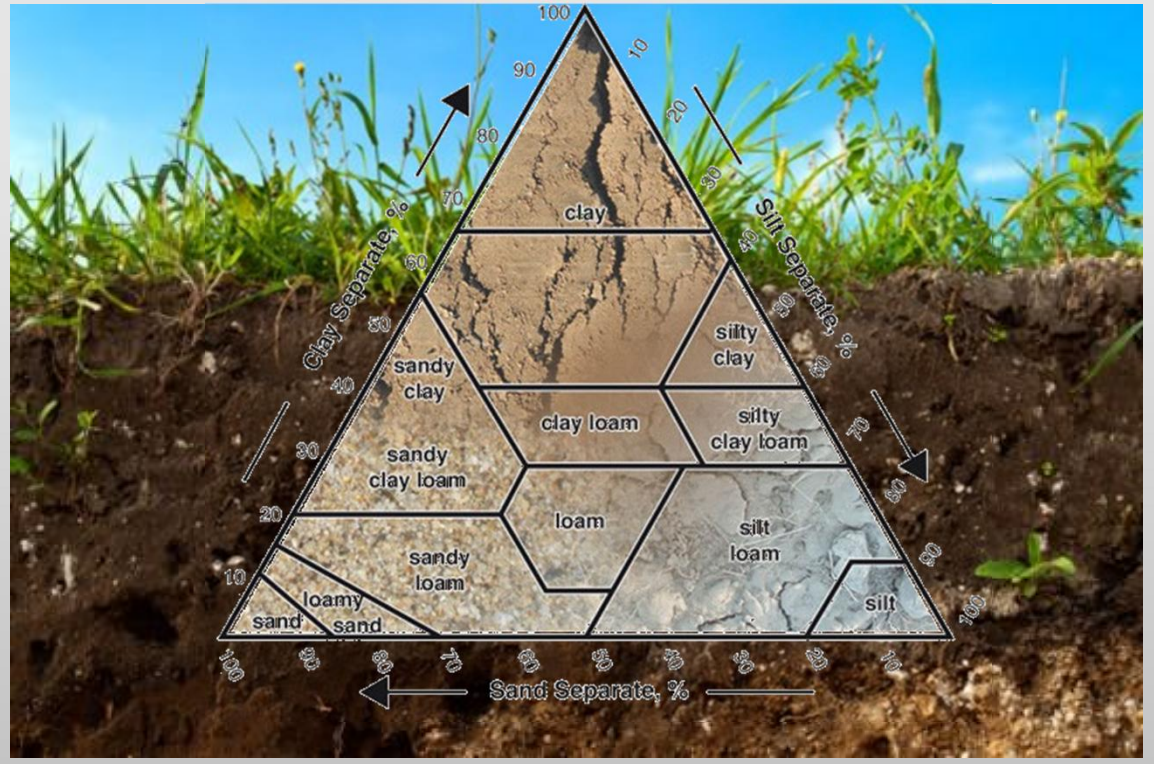
- Why do we need to disinfect the soil ? to favour farming
- Attual methods: pesticides (e.g.Toxaphene [1]), bioremediation (using other antagonist biological organisms, e.g. Lumbricus terrestris and Coccinellidae [2]-[3])
- Other Methods: Microwaves Power

[1] J. Bezchlebová, J. Černohlávková, J. Lána, I. Sochová, K. Kobetičová, J. Hofman, "Effects of toxaphene on soil organisms," *Ecotoxicology and Environmental Safety,* vol. 68, no. 3, pp. 326-334, 2007.

[2] C. Bonaventura, F. M. Johnson, "Healthy environments for healthy people: bioremediation today and tomorrow," *Environmental Health Perspectives*, vol. 105, Suppl. 1, pp. 5, 1997.

[3] W. Devliegher, W. Verstraete, "The effect of Lumbricus terrestris on soil in relation to plant growth: effects of nutrient-enrichment processes (NEP) and gut-associated processes (GAP)," *Soil Biology and Biochemistry*, vol. 29, no. 3, pp. 341-346, 1997.

Soil



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

STEPS

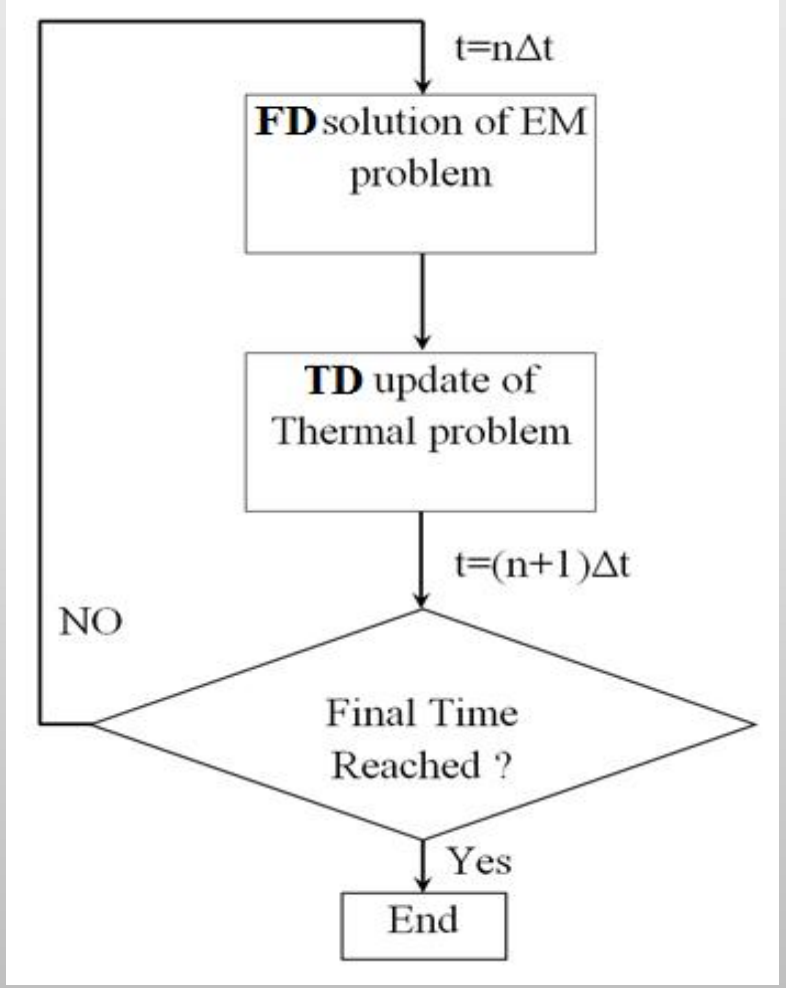
I. Compute the dielectric constant of soil as function of temperature

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 distribuiton by solving the Heat Transfer Equation with FDTD method

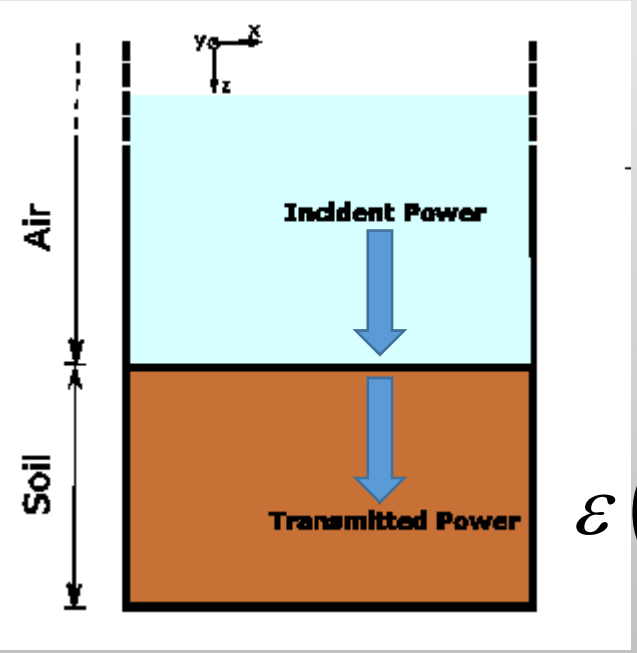

t=nΔt
FD solution of EM problem
TD update of Thermal problem
t=(n+1)Δt
NO
Final Time Reached ?
Yes
End

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*.
- $z > z_\infty$, $T = T_0$ $\forall t$



$$\varepsilon(z)$$

Dielectric Constant of Water (Ray, 1972)

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

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

P. S. Ray, “Broadband complex refractive indices of ice and water,” *Applied Optics*, vol. 11, no. 8, pp. 1836-1844, 1972.

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

$$\frac{dE(z)}{dz} = -j\omega\mu_0 H(z)$$

$$\frac{dH(z)}{dz} = -j\omega\varepsilon[z,T(z)]E(z)$$

$$Z(z) = \frac{1}{\zeta}\frac{E(z)}{H(z)}$$

An effective solution starts from the computation of by a backward numerical integration of the complex Riccati equation:

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

$$\frac{dE(z)}{dz} = -j\omega\mu_0 H(z) = -j\omega\mu_0\frac{E(z)}{\zeta Z(z)}$$

Heat Transfer Equation

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

- T : temperature [°K];
- ρ : soil density [kg/m^3];
- C : specific heat at constant pressure [W/m·K];
- κ : soil thermal conductivity [J/kg·K];
- P_T: Thermal Power generated during MW irradiation [W/m^3];

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

T_A *is the external air temperature.*

h_c *is the heat transfer coefficient in* $W\ m^{-2}K^{-1}$.

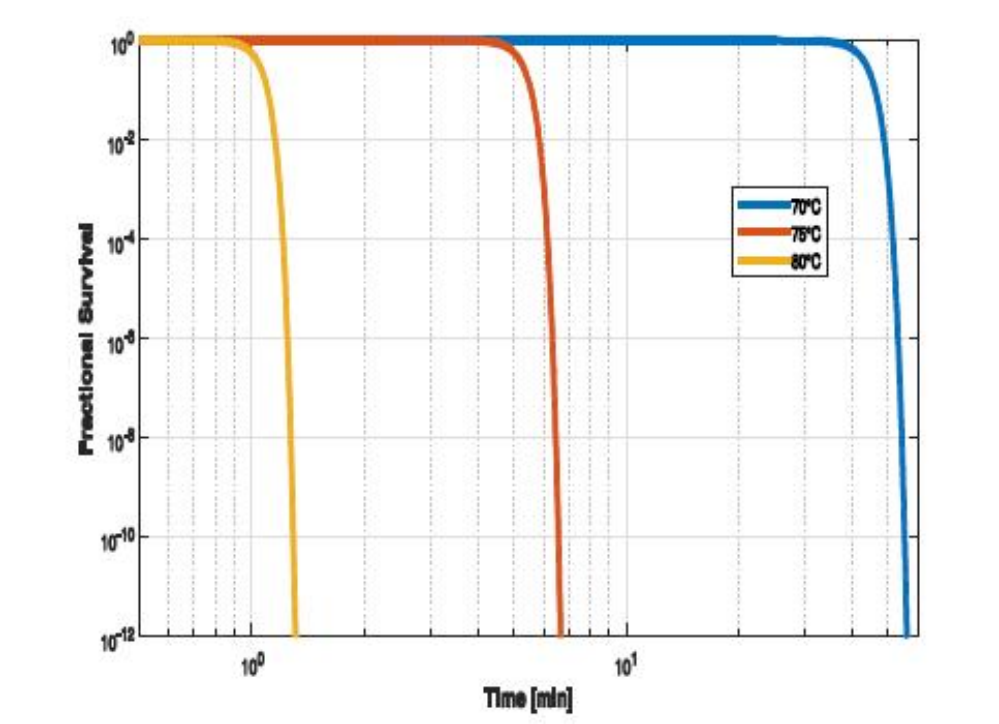
FDTD SOLUTION OF HEAT TRANSFER EQUATION

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

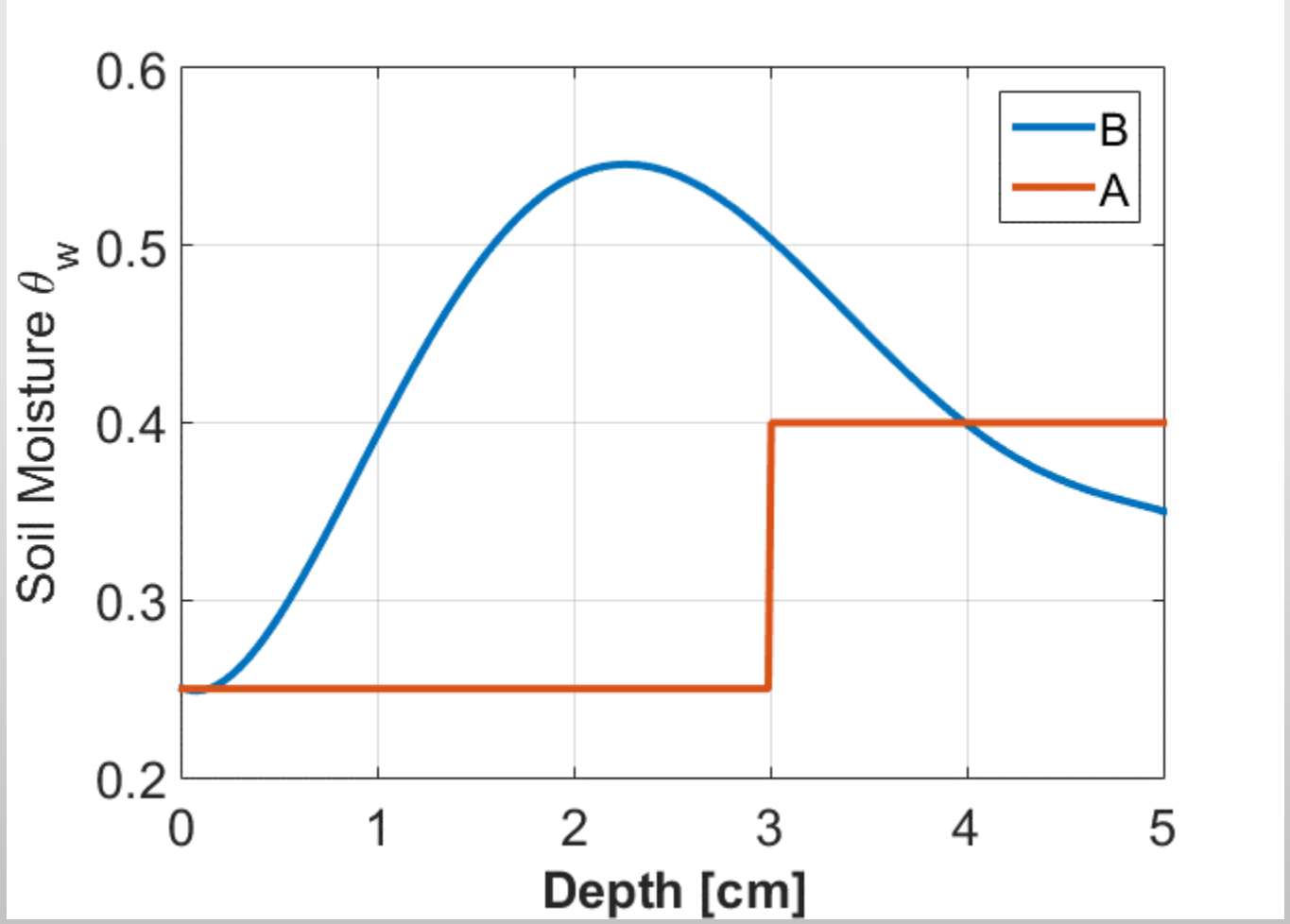
$$T_{1,n} = T_{0,n} + \frac{h_c \Delta z}{\kappa[0, T_{0,n}]}(T_{0,n} - T_A) = \left(1 + \frac{h_c \Delta z}{\kappa[0, T_{0,n-1} + T_A]}\right) T_{0,n} - \frac{h_c \Delta z}{\kappa[0, T_{0,n}]} T_A$$

THERMAL DISINFECTION CONDITIONS

Survival of *Fusarium oxysporum* as a function of time at different

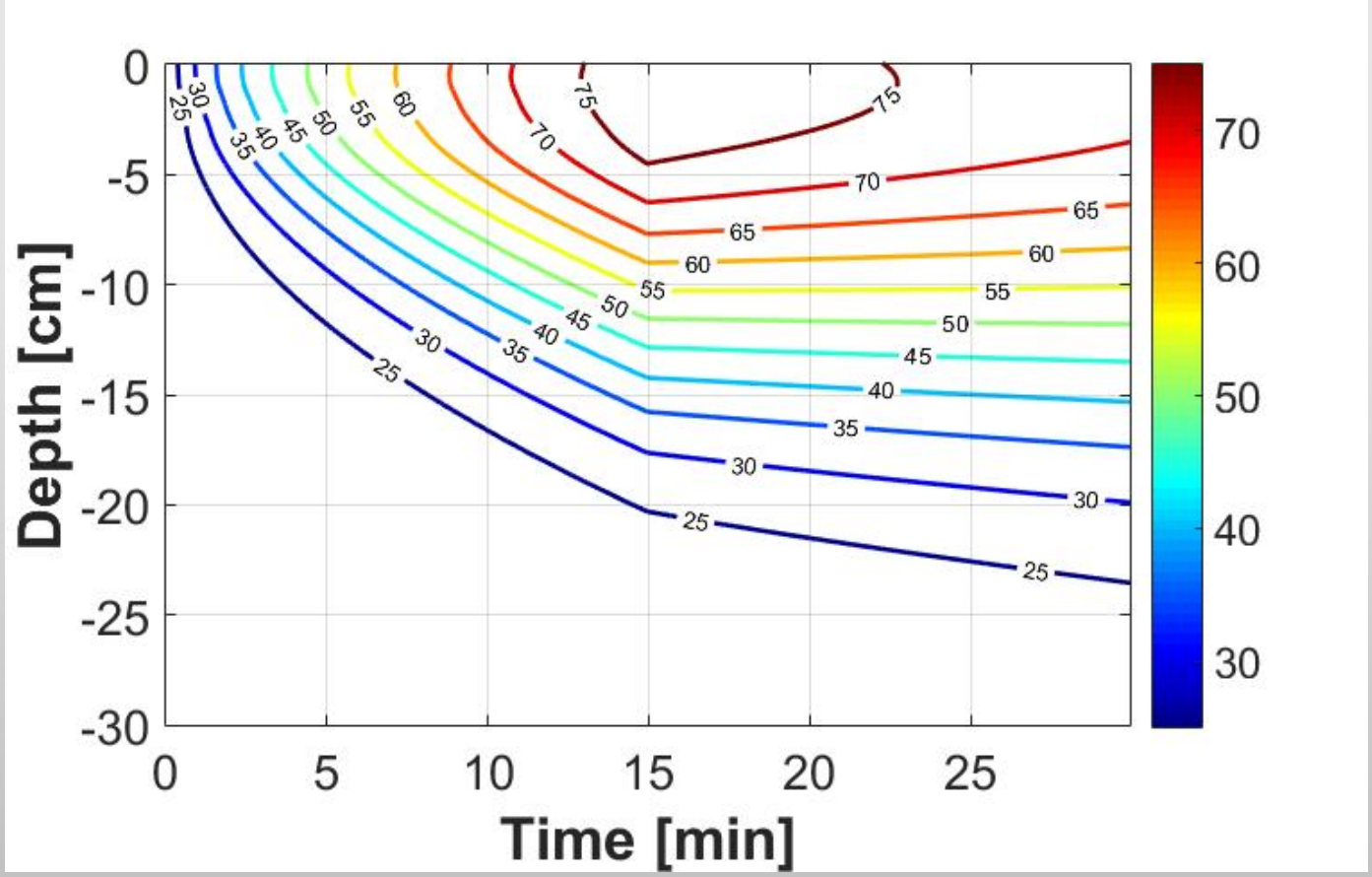


E. Shlevin, I. S. Saguy, Y. Mahrer, J. Katan, "Modeling the survival of two soilborne pathogens under dry structural solarization," *Phytopathology*, vol. 93, no. 10, pp. 1247-1257, 2003.



Soil moisture distribution used in the tests

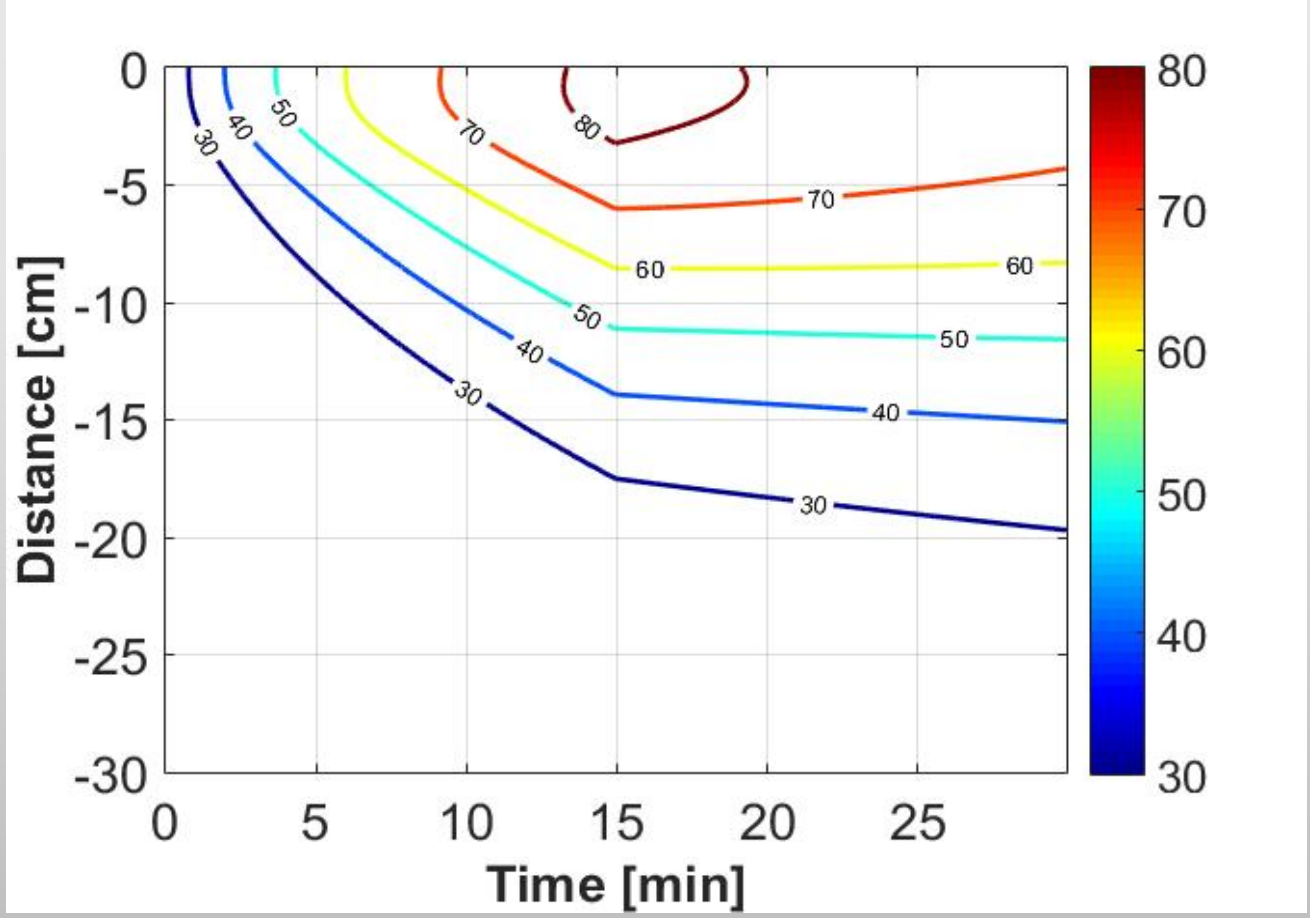
RESULTS



Fields	A
Sand [%]	29
Silt [%]	50.1
Clay [%]	20.9
Long.	9.166919204°
Lat.	39.70296945°
ρ	1400 kg m^{-3}
C [@20°]	893 J $kg^{-1}K^{-1}$
k [@20°]	2.47 W $m^{-1}K^{-1}$
h_c [@20°]	2.0 W m^{-2} K^{-1}

Soil temperature distribution for field A, for soil moisture distribution B.

RESULTS



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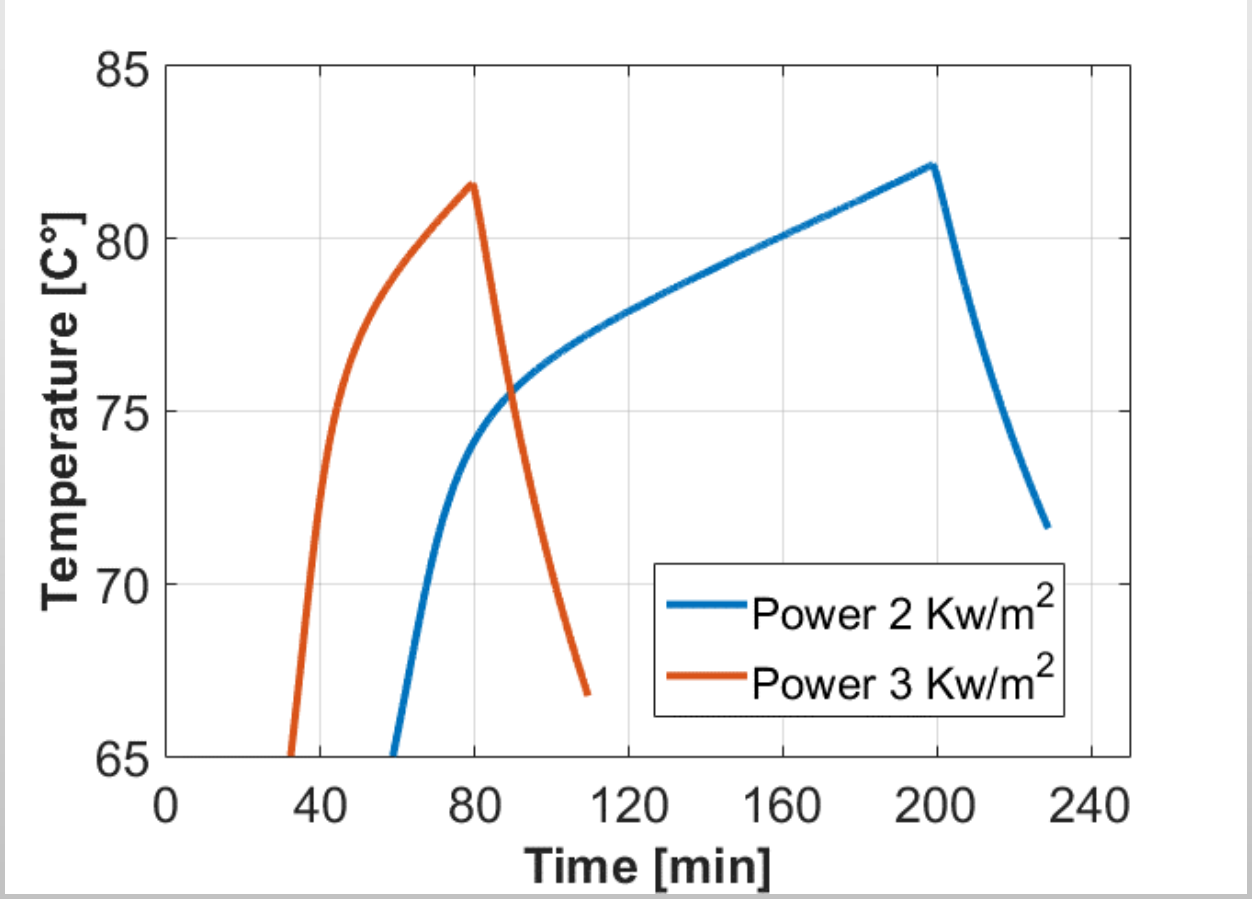
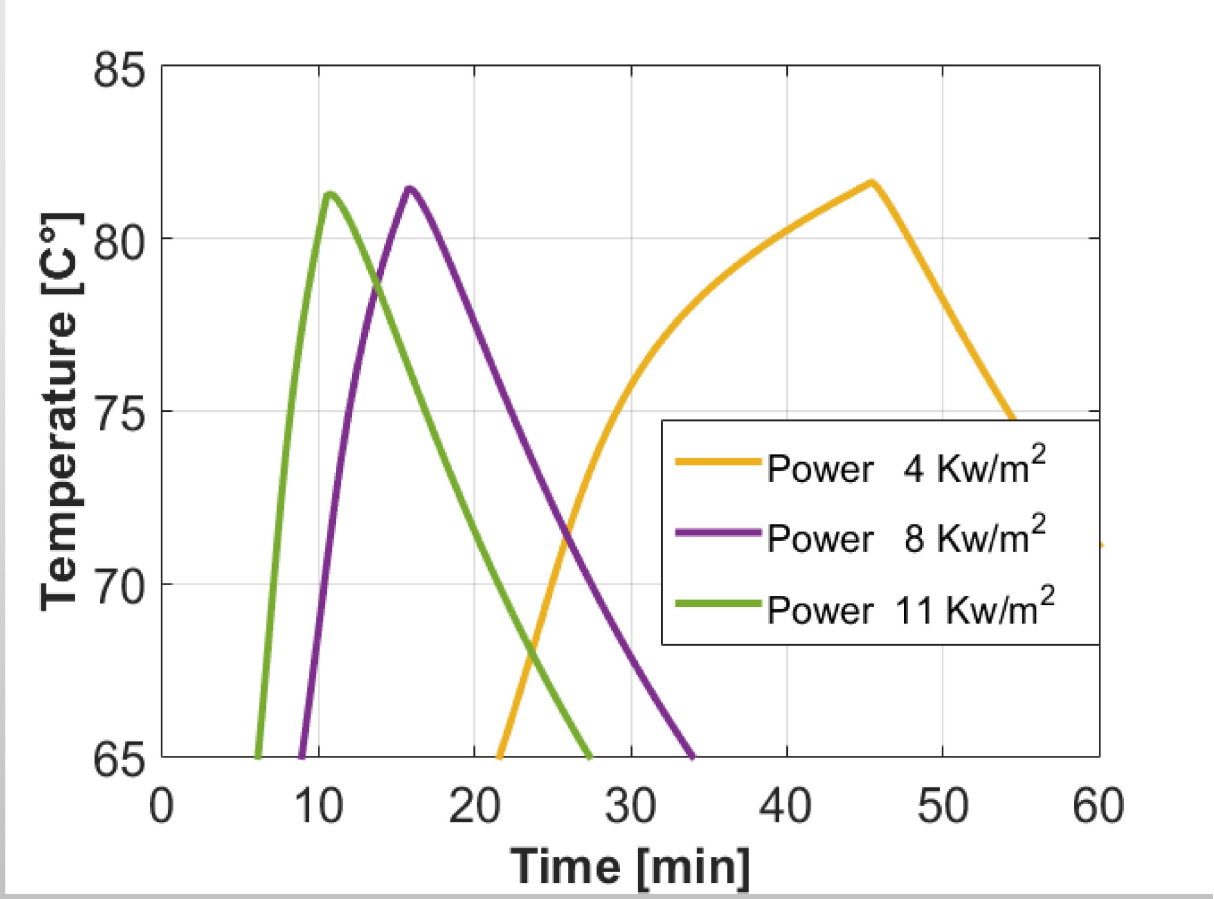
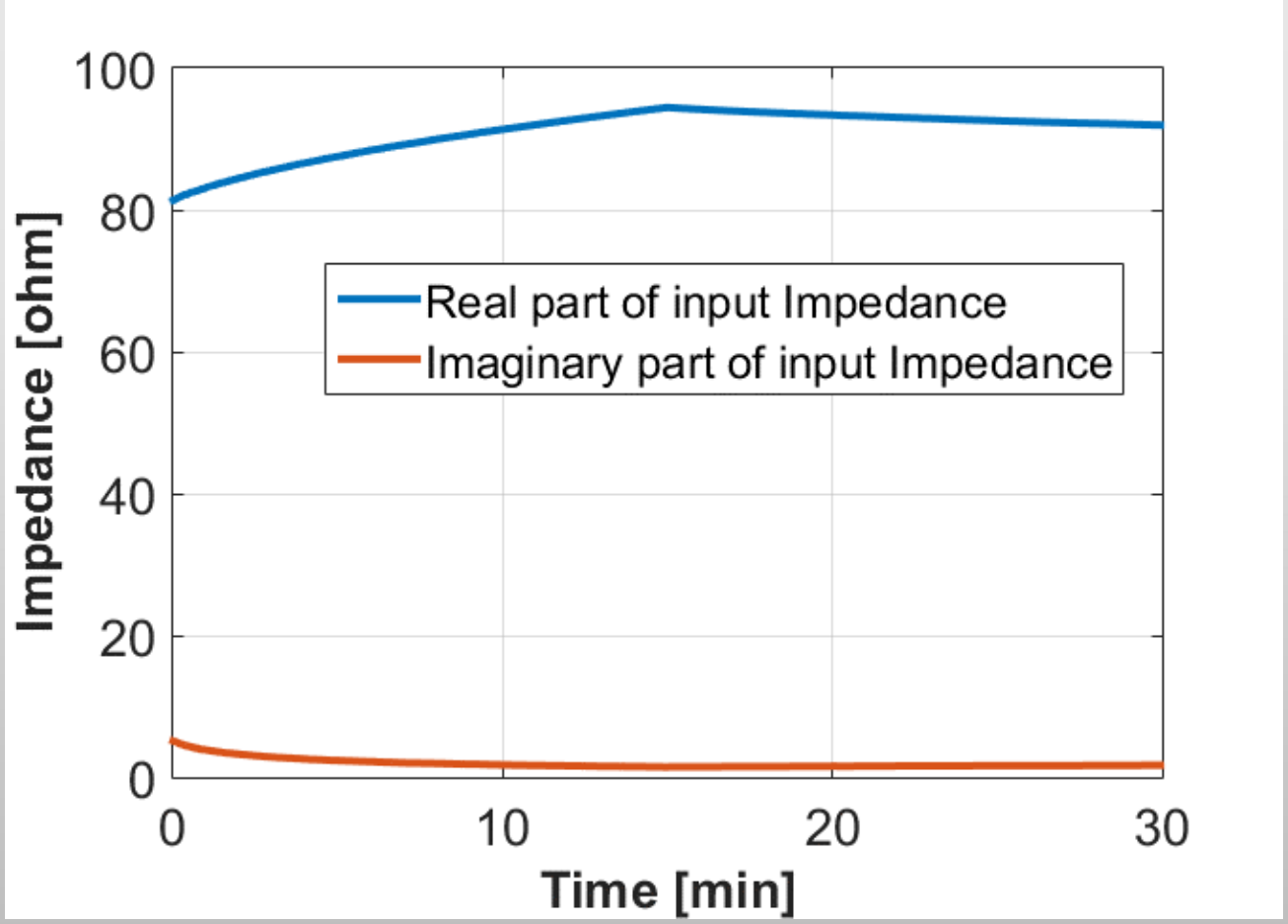




Surface temperature distribution for different power densities, for the humidity distribution shown as “profile B

RESULTS


100
80
60
40
20
0
0
10
20
30
Impedance [ohm]
Time [min]
Real part of input Impedance
Imaginary part of input Impedance

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