A Novel Device for the Soil Sterilizing in Sustainable Agriculture

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Abstract. In this paper a machine that performed the soil sterilization has been designed. The soil is cut and put in a loading hopper and downloaded in a rotating cylinder placed on the machine. The fins located inside the rotating cylinder performed the crushing and the mixing of the soil. Each soil particle through the temperature field ranged between 290–1900° C for 3–5 min and a preset output soil temperature of 130–140° C is reached and discharged downward. It maintained the process temperature long enough, to allow the elimination of the infesting organisms located in the considered soil.

Keywords: Soil thermal exchange · Soil sterilizing · Soil sterilizing machineries

1 Introduction

The soil thermal sterilization [1–3] consists of temperature increasing of each soil particle up to a determined value [4, 5], for a sufficient time to reduce the bacterial load [6]. It has been observed by different authors [7, 8], that the decrement of the cells of a microorganism, it follows a kinetics of the first order,

$$\frac{dN}{dt} = -kxN \tag{1}$$

where N is the number of cells present and the constant k (constant of extinction) it depends from the type of microorganism and temperature [9]. It is defined Thermal Death Time (TDT), the necessary time to kill a determined number of microorganisms at a specific temperature, and it is time range corresponding to 12 times the time of decimal reduction:

$$TDT = 12 \times D \tag{2}$$

where D is the time of decimal reduction or the time required to destroy the 90% of the microorganisms [10–13]. In Table 1, temperature-time conditions necessary for the eradicating in 10 min of some vegetable pathogens are reported [14, 15]. One of the

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problems encountered during the soil thermal disinfestation is due to the fact that the soil is a bad heat conductor.[16, 17]. Indeed, the need arises to obtain that every single particle of soil reaches the sterilization temperature, avoiding thermal gradients in the soil to be sterilized [18]. Addressed in such sense, a soil sterilizing machine has been set up [19].

Table 1. Temperature-time conditions for the eradicating of some vegetable pathogens (in 10 min).

Pathogens	Temperature	Reference
Sclerotiniasclerotiorum	60° C	[15]
Sclerotiumcepivorum	50° C	[15]
Verticilliumdahliae	55° C	[15]
Fusariumoxysporumf.sp.lycopersici	60° C	[15]
Fusariumoxysporumf.sp.lactucae	60° C	[15]
Pythium ultimum	60° C	[15]
Erwiniaamylovora	55° C	[15]
Elateridi	50° C	[15]

2 Materials and Methods

It has been designed and realized a prototype of soil sterilizing machine (Figs. 1 and 2). It is constituted from: a system to cut, remove and carriage the soil, in continuous way, toward the hopper of the rotating oven; a rotating oven installed on a self-propelled structure (or hauled) with a downloading system of the sterilized soil [20, 21].

Fig. 1. Scheme of the soil sterilizing machine

During the operative phase a portion of cut soil is submitted to a crushing and remixing action that happens inside the rotating cylinder (rotating oven), provided of special inside ribs [22, 23]. Insofar the soil final temperature depends on the crossing speed of the rotating oven [24–26]. The soil-treated downloading system has been modeled by

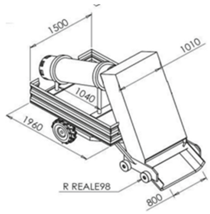

Fig. 2. Scheme of the soil sterilizing machine

numerical code Solid Works 2011 [27]. To evaluate and to optimize the soil permanence times in the cylinder and the cylinder slope, thermodynamic numerical simulations have been performed by the code ABAQUS 6 [28]. Experimental tests have been performed by using the considered machine, [29] with two different typologies of soils:

- type A (sand 83%, silt 2%, clay 15%) with moisture values of 17, 18, 18.4 and 21.5%;
- type B (sand 42%, silt 23%, clay 35%) with moisture values of 17, 18, 19 and 21%.

The values of thermal conductibility and thermal capacity for the two soil typologies are: type A: thermal conductibility 0.8 W/mK and thermal capacity 1.4 MJ/m^{3}K; type B: thermal conductibility 1 W/mK and thermal capacity 1.5 MJ/m^{3}K. Further, the cooling curve for the two soil typologies considered has been evaluated, starting from an initial temperature of 121° C [30]. A soil mass contained in a volume of a cube with a side of 40 cm has been considered [31]. Such soil volume has been arranged on trays on which a soil layer of 0.5 cm has been formed, so that to avoid, at the most, the thermal gradients inside the soil layer and to obtain a soil temperature the more possible uniform [32]. Such trays have been put in heater and heated up to a temperature uniform of 121° C. Such heated soil has been put, then, in the cube with a side of 40 cm and inside it, 3 thermocouples have been located: the first one at a depth of 2 cm, the second at 2 cm from the bottom (depth 38 cm), and the third at a depth of 20 cm. The environmental temperature was of about 20° C. The test has been repeated 3 times for both the soil typologies, detecting a maximum difference lower than 5% [33, 34]. The cooling curve of the 1° thermocouple has been considered, (it cools more quickly in comparison to the others) and therefore the mean values of the temperatures detected by the 1° thermocouples during the cooling of the considered soils have been reported [35]. To evaluate the effectiveness of the sterilizing action of the considered machine, comparison between not-treated and treated soils have been performed, by mean the analysis of the microbiological and chemical effects on the micro-fauna, due to the treatment performed [36]. The soil samples used for the analyses, have been obtained by a protocol, for which for the considered area, 3 sub-samples at three different depths (10 cm 20 cm, 30 cm) have been withdrawn, and 3 samples with volume of 0.5 dm^3 have been obtained [37].

3 Results and Discussion

By the performed thermodynamic analysis, it has been possible to obtain the temperatures distribution inside the rotating oven considering 30 turns per minute; slope of 15° (Fig. 3)

[38, 39]. The soil quantity treated has been of 0.030 m^3/s. In the operative conditions, the soil crossed the whole cylinder in 3–4 s around, and the final temperature of the considered soil has been of around 80° C. The flame escapes from a burner with circular section, with diameter of 150 mm, and the length of the flame, in the operative conditions considered, it is of around 500 mm and that the flame has a geometric shape similar to half-ellipsoid, with smaller diameter of 150 mm and greater diameter of 1000 mm [40].

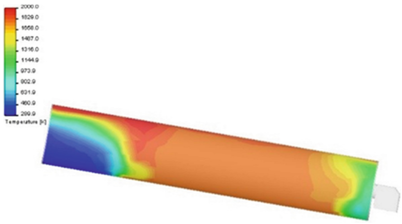

Fig. 3. Temperatures distributions inside rotating oven obtained by numerical simulation

Therefore, it has been reported the curve detected by the thermocouple n. 1 (Fig. 4) [41].

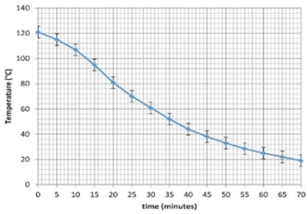

Fig. 4. Mean cooling curve of the considered soils

The tests were repeated three time and the maximum error value detected was less than 5%, and it was reported with error bar in Fig. 4. These data show us as, considering a determined pathogen, whose TDT is 60° C for 10 min, to perform the total eradicating of it, from the considered soil, it is necessary to heat the soil up to temperature of around 80° C, in this way the considered soil has for 10 min, the temperature greater than 60° C. In fact, according to the soil cooling curve calculated, after about 10 min the soil will reach the temperature of 60° C, fully satisfying the conditions of temperature-time for the eradicating of the pathogen reported in Table 1, from the considered soil [42, 43]. During the experimental tests performed, all the examined soils had an initial temperature around the 20° C, and they have been heated up to the temperature of around 80° C, with an increase of temperature of around 60° C [44]. The considered soils, with initial moisture ranged between 17 and 21%, after the treatment, they have made to notice a loss of the 3–4% of water. [45]. At the soil moisture is added the quantity of water present in the fuel and also that, during the process of combustion is formed [46]. In the table are reported the operative parameters values detected before and after the soil treatment, for the soil types considered [47]. Every experimental test has been repeated three times. The maximum difference among the obtained results was lower than 5%, for which in the following Table 2 the mean values obtained have been reported.

Table 2. Experimental results obtained by soil sterilizing tests

T	Soil type	T_i °C	T_f °C	ΔT °C	U_i %	U_f %	ΔU %
1	A	20,0	80,0	60,0	18,0	14,7	3,3
2	A	22,0	81,0	59,0	18,4	15,9	2,5
3	A	19,0	79,0	60,0	21,5	19,0	2,5
4	A	21,0	82,0	61,0	17,0	14,0	3,0
5	B	21,0	82,0	61,0	21,0	18,0	3,0
6	B	20,0	80,0	60,0	21,0	17,0	4,0
7	B	22,0	81,0	59,0	18,0	15,0	3,0
8	B	19,0	79,0	60,0	19,0	15,0	4,0

$T_{initial}$ = initial temperature of the soil; T_{final} = outlet soil temperature (at the output of the rotating cylinder); $\Delta T = (T_{final} - T_{initial})$; U_i = initial soil moisture percentage (moisture mass content in the soil/ total mass*100) (kg/kg); U_f = final soil moisture percentage (at the output of the rotating cylinder). A T-statistic with a probability of 95% was performed on each group of samples, and has led to detect, in the soil treated, a decrement of the total microbial load until zero or at few unities has been obtained [48] (Table 3).

Table 3. T-statistic with a probability of 95% for A and B Tests

	ΔT(°C)	$\Delta U = U_i\text{-}U_f(\%)$
Experiment A	60,0 ± 1,3	2, 8 ± 0, 6
Experiment B	60,0 ± 1,3	3,5 ± 0, 9

Besides the heating and the loss of water in the test's conditions performed, they have not involved meaningful transformations in the structure of the mineral, in the fraction of the clay [49–51].

4 Conclusions

A soil sterilizing machine has been set up with a working capacity of 360 m^2/h. It has been verified the effectiveness of the treatment of soil sterilization [52]. Besides with such machine, the time necessary to perform the soil sterilizing, is reduced in way that, it does not fear comparisons with other chemical methods traditionally used [53, 54].

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