Effect of Solar Concentrator System on Disinfection of Soil-Borne Pathogens and Tomato Seedling Growth

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1. Introduction

The development of non-imaging reflectors for circular-cylindrical solar energy receivers has consisted primarily of investigations on symmetrical V-trough and compound parabolic concentrator (CPC) designs, with the latter being favoured recently because of its superior optical collection. However, it has since been realised that asymmetrical versions of such reflectors may be developed and that they have their own limits of concentration and ideality. It was shown that ideal asymmetrical reflectors could achieve substantially greater peak concentration than symmetrical reflectors of the same acceptance angle (Mills and Giutronich, 1979). An important difference, however, is that the performance of the asymmetrical reflector is much higher at one solstice than another because the aperture is adjusted with respect to the acceptance angle envelope. With an asymmetrical collector, the possibility is presented of at least partial bias of the seasonal collector output toward the maximum load period. Such a bias would reduce dumped solar energy in low load periods, allowing a larger usable solar fraction of energy supplied. Phitthayarachasak (Phitthayaratchasak et al., 2005) upgraded the solarization system process to increase its efficiency by applying the asymmetrical compound parabolic concentrator (ACPC) to enable the concentration of more solar radiation by an average of up to 2.5 times. It is convenient to operate because there is no need to adjust the angle of the ACPC unit according to the movement of the sun. The result showed that the soil temperatures at various depths were high enough to inhibit the growth of microbes within a 5 day period. The solarization operating time was distinctly decreased. The solarization system is then a suitable process for destroying or inhibiting the growth of soil microbes which cause plant diseases (Burrafato, 1998; Le Bihan et al., 1997; Bell; 1998). Even though this system is easy to conduct, with less cost, and no pollution, it still needs 4–6 weeks to operate. Therefore, in this study, the CPC combined with an ACPC unit was developed in order to decrease the time for soil microbe inhibition to be closer to the time of traditional steaming methods.

2. Aim

The aim of this work is to study solar system treatments: solarization with ACPC, and CPC combined with ACPC and hot water. In addition, the effects on *Erwinia cartoverora* population in the soil and tomato seedling growth are also studied.

3. Methods

3.1 Design of the asymmetry compound parabolic concentrator (ACPC)

In general, a symmetrical compound parabolic concentrator (CPC), as shown in Fig. 1, comprises two identical parabolic reflectors which are usually oriented along an east-west axis while an axis of the CPC points toward the sun. For such a system to achieve maximum annual sunbeam on a focal plane, it requires an accurate sun tracking system and hence, additional cost. Moreover, a north-south tracking angle adjustment is also needed seasonally. With a modification of the traditional CPC, asymmetrical compound parabolic concentrator (ACPC), on the other hand, has different height of a parabola reflector on each side which allows for a longer time for incident solar irradiance beam on the reflectors without tracking, and hence, more heat would be absorbed on the focal area.

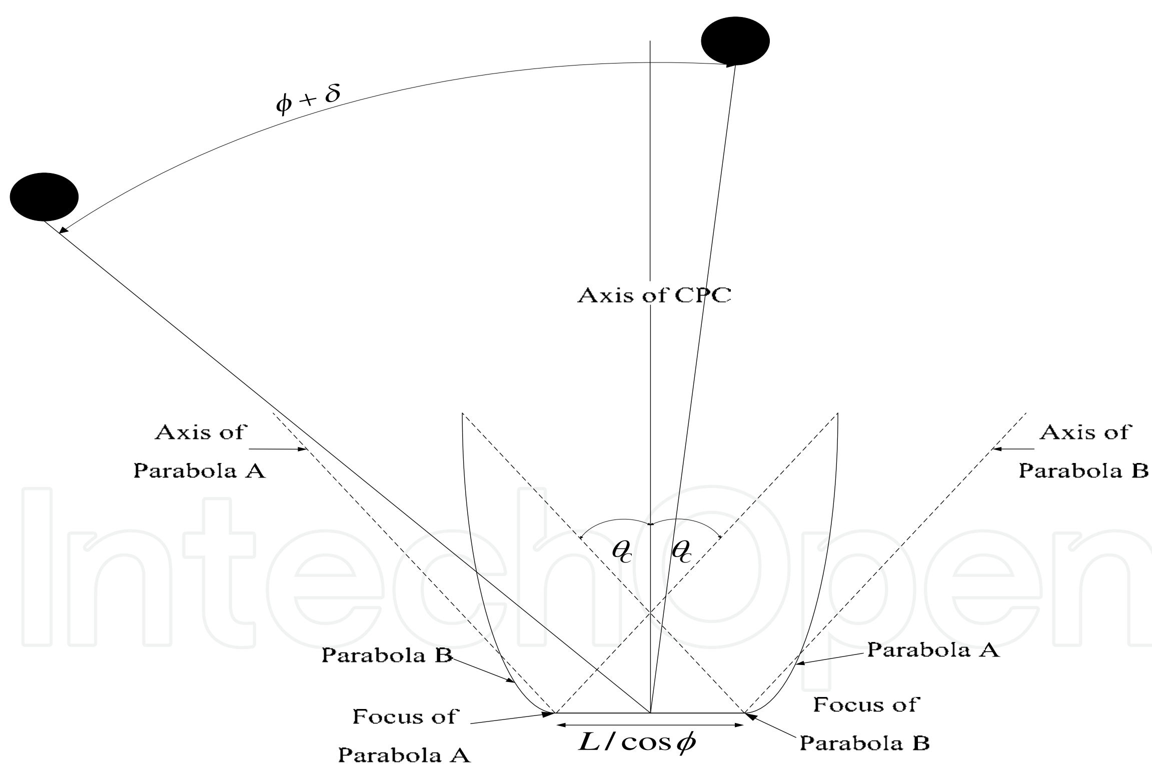


Fig. 1. Typical symmetrical compound concentrator and incident irradiance with its reflection beam on focal plane.

In this study, the ACPC is designed based on Bangkok location (latitude, $\phi = 14^{o}$ N). Due to the rotational axis of the earth with 23.45° inclination respect to the orbital plane around the sun the angle of the sun above equatorial plane, declination angle, varies along with the day of the year and can be determined by

$$\delta = 23.45 \sin\left[360\frac{(284+n)}{365}\right]$$

Where

δ = Declination (degree); $-23.45^\circ \le \delta \le 23.45^\circ$
n = Julian day (January 1, n = 1)

According to the setting position of ACPC and the declination axis, the sun position will be at an angle of $(\delta + \phi)$. Therefore, for Bangkok, the angle of incidence is in between -9.45° and 37.45°. In this research, the acceptance angle of APAC, θ_c = 21° is selected to obtain a solar incidence angle from -7° to 35° in the 2 periods: 13 Jan – 24 May and 22 June – 20 Dec without the axis adjustment.

Theoretically, there are 3 possible cases for the reflections of radiation beams on the CPC

1. $\theta < \theta_c$ Radiation reflection in between the two focal points of CPC
2. $\theta = \theta_c$ Radiation reflection at the focus of CPC
3. $\theta > \theta_c$ Radiation reflection off the focus outside CPC

In this design, the angle of radiation incident beam and the axis of the CPC, θ_c, are considered. As the angle of the radiation incident on one side of the CPC decreases ($\theta < \theta_c$) it will increase in the radiation on another side of the CPC. To gain more radiation reflection on the soil the axis of the CPC is pointed to the sun and the focal point of CPC is moved into the soil. The ACPC then has a large parabola on one side and a small one on the other side. The design and calculation of the ACPC is shown as below.

1. Large Collector Design

In this design, the CPC has a flat receiver as shown in Fig. 2 for which all parameters can be calculated using the following formula

$$H = \frac{a}{2}\left(\frac{1}{\tan\theta_c} + \frac{1}{\tan\theta_c \sin\theta_c}\right)$$

$$f = \frac{a}{2}(1 + \sin\theta_c)$$

$$A_a = \frac{a}{\sin\theta_c}$$

With the given design parameters, the projected area of the solar radiation on the receiver, a = L/cosØ with L = 1 m and a latitude, Ø of Bangkok = 14 degrees one can obtain H=5.09 m, A_a = 2.88 m and f = 0.699 m. According to Fig. 2 (Duffie & Beckman, 1991), the relationship between a ratio of receiving height and aperture area, H/A_a, and a concentration ratio, CR with H/A_a = 1.77 results in CR = 2.80. Then, the edge of CPC was cut to fit the application by theoretically reducing H/A_a to 50%, which is 0.885, and this gives CR=2.4. Afterwards, the CPC was tilted to Ø degree with a horizontal plane to obtain the focal point at Ltan = 0.25 m as depicted in Fig 3 (The CPC height reduced from 1.45 m to be 1.20 m with the acceptance aperture is 1 m).

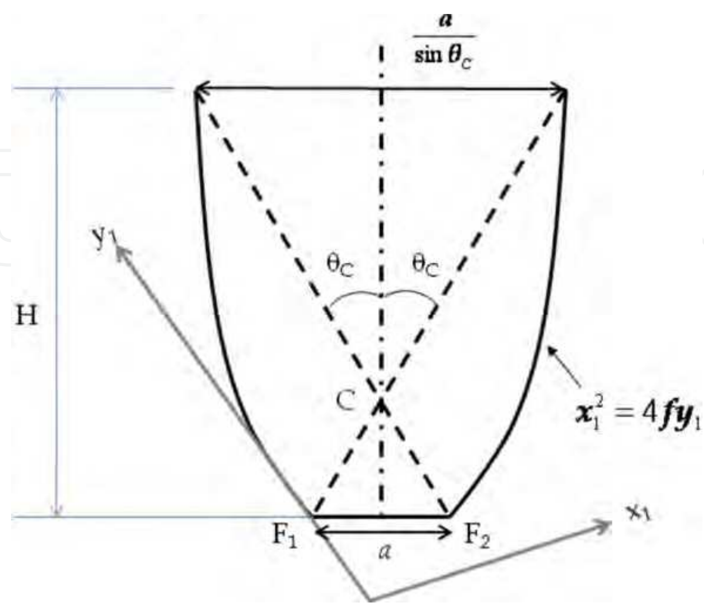


Fig. 2. Design parameters of Flat-Plate receiver CPC.

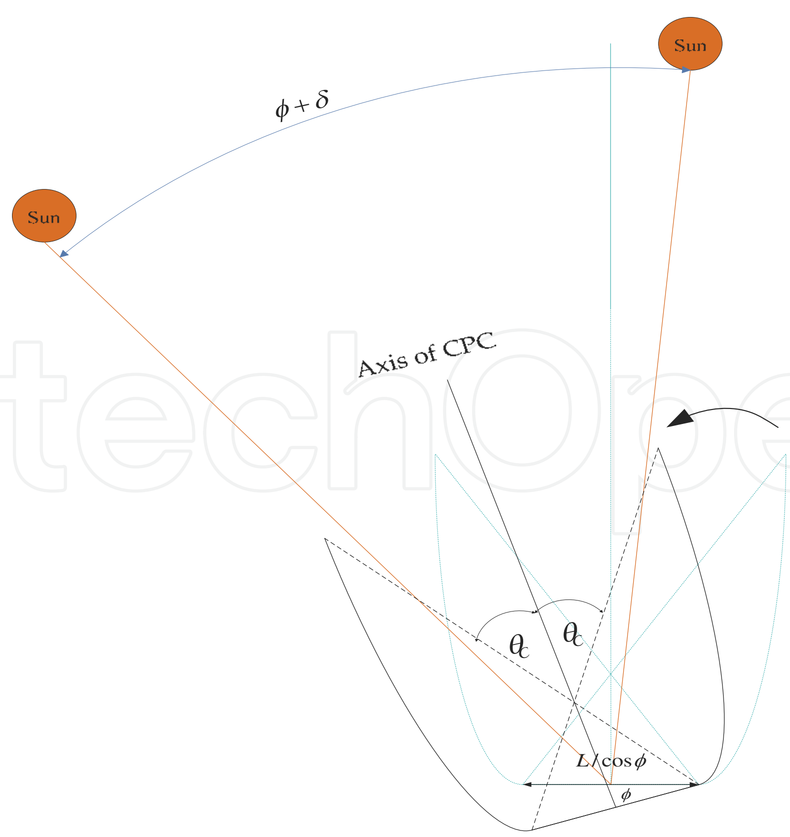


Fig. 3. An inclined CPC at angle Ø with horizontal plane to maximize the incident radiation.

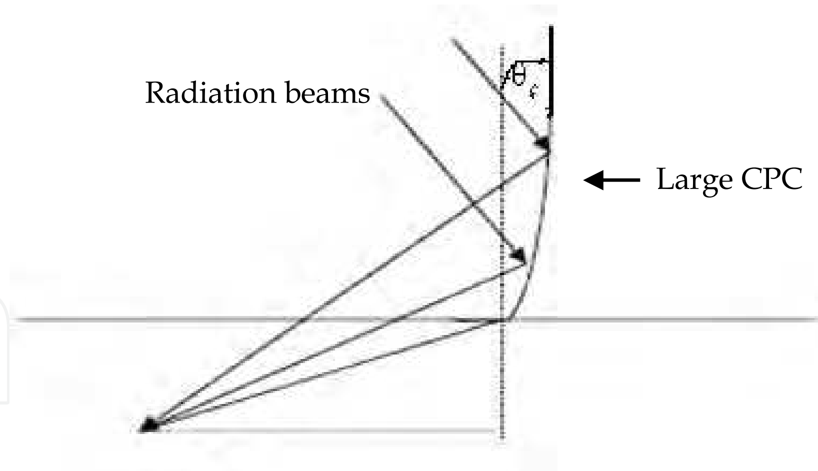
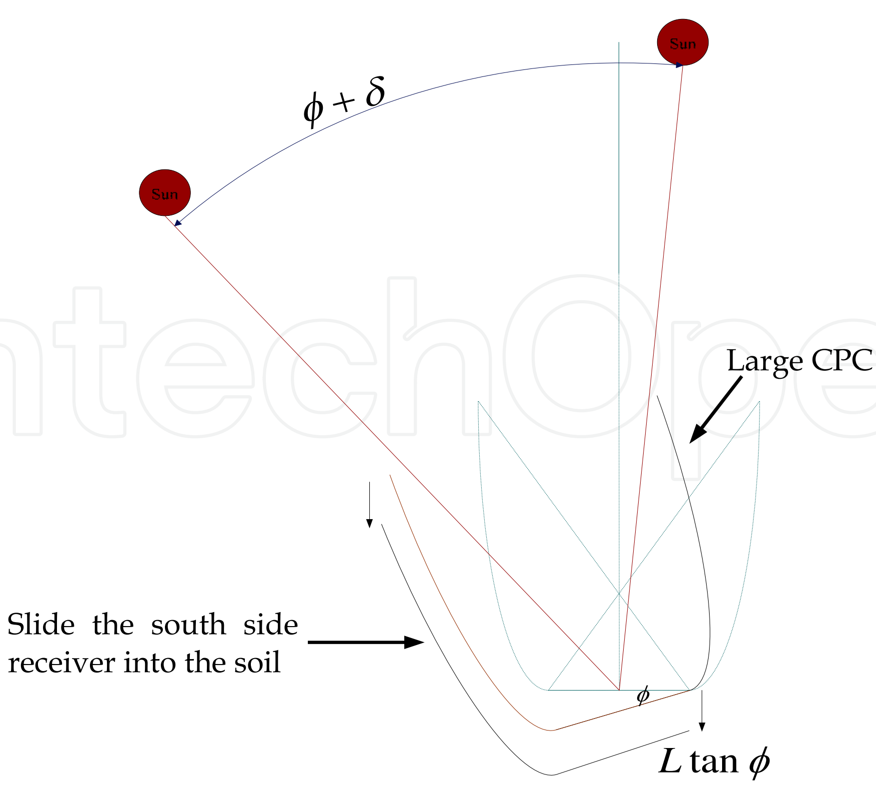


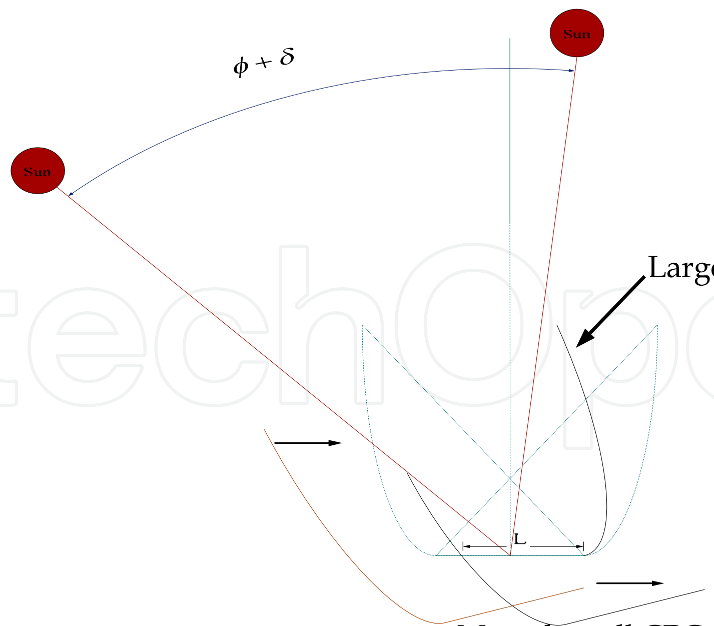
Fig. 4. A reflection of beams from CPC when the radiation beam is incident on a reflector.

2. Small CPC Design

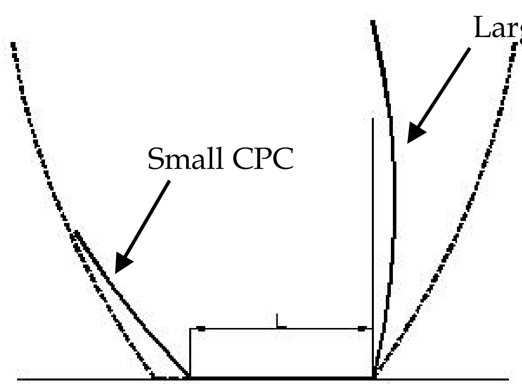
The key point of the design is that the focal point of the small CPC must be the same as that of the large one while one of its curved sides is buried in soil angled at Ø with the ground level. The depth (L/cosØ) is 1 m. Consequently, the height of the small CPC reduces to 0.25 m. Then, the focus is horizontally adjusted until the edge of the large CPC reflector is onto the edge of the receiver or at a distance of L from that of the large one on the soil surface. The finished assembly of the ACPC, shown in Figs. 5 and 6 depicts the reflection path in ACPC.



a) A South-side receiver is inclined and buried in the soil at the depth of Ltan Ø.



b) Move to the North for a distance L.



c) Asymmetrical compound parabolic concentrator (ACPC).

Fig. 5. Asymmetrical Compound Parabolic Concentrator (ACPC) assemble procedures.

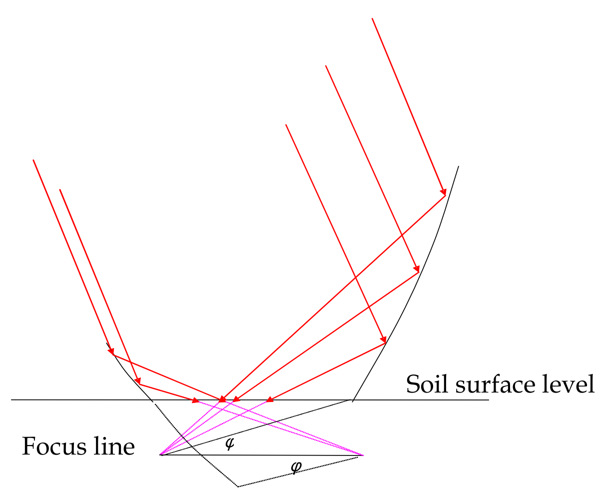


Fig. 6. Radiation beam and its reflections from asymmetrical CPC on soil surface.

Fig. 7. Installation of ACPC.

3.2 Upgrading the ACPC unit with water boiler and CPC

The ACPC unit was capable of boiling water simultaneously while operating the disinfection process by using the heat from the ACPC panel because the surface has a high temperature. The process was operated by using copper tubes with the surface cut into a semicircle in order to increase larger spaces to absorb the heat, and fix them at the back side of the ACPC panel. A further step to increase the efficiency of the heating process, the hot water from ACPC panel in the copper tube was treated by CPC before the hot water outlet was fed into the soil plot.

When sunlight hits the ground it is partly reflected and partially absorbed by soil. The absorbed heat increases the soil temperature and is then transferred down into a deeper level. As soil has low heat conductivity the heat transfer is considerably poor. Increasing temperature of water droplets can obtain higher soil temperatures at the deeper level from the surface as water can diffuse through small pores and heat up the soil grains via conduction and convection processes.

The solarization process normally takes 4–6 weeks for the temperature to increase and induce lower levels of soil to be able to inhibit microbes which cause crop disease. In consequence, the ACPC unit is introduced to collect solar energy to provide higher temperature which can reduce the length of time of the solarization process down to 5 days. However, this time period is still not appropriate for industrial crops. Hence, the need for further improvement of the ACPC unit’s capability to boil water simultaneously while operating the process. The hot water is then used to drip into the soil. It also gives moisture to the soil which absorbs the heat from the hot water to increase its own temperature. Furthermore, because the dripping water is hot, it is guaranteed not to have any microbes.

3.3 Experimental design and soil treatment

All the experiments were carried out under sunlight. For soil solarized plots, transparent polyethylene sheets 0.05 mm thick were used. Soil treatment was performed for 1 day starting from 8:30 am to 4:45 pm in April. Soil temperatures at depths of 0 cm, 10 cm, 20 cm, 30 cm and 50 cm were monitored by means of shielded copper-constantan thermocouples. The analog signals from the sensors were converted into digital signals. The output data were printed continuously (24 h) on an hourly basis using a computer connected on-line with the data acquisition system.

In this study, four vessels with diameters of 32 and 69 cm high were filled up with soil, which was then watered and left for 2 days to prepare the soil ready for planting. The thermocouples were set at the depth levels of 0, 5, 15, 30, and 50 cm in the centre of the vessels. The 100 watts of electric light to replace solar radiation (due to the lamp's heat is almost the same heat level of the solar radiation effected to the soil surface) was set at the height of 10 cm above the soil surface at the centre point of the vessels. The 60°C hot water from the boiler (its temperature is almost the same as its effect from ACPC) was then dropped at speeds of 12, 16 and 20 cc/min into the vessels number 2, 3, and 4, respectively for 5 h as shown in Fig. 8.

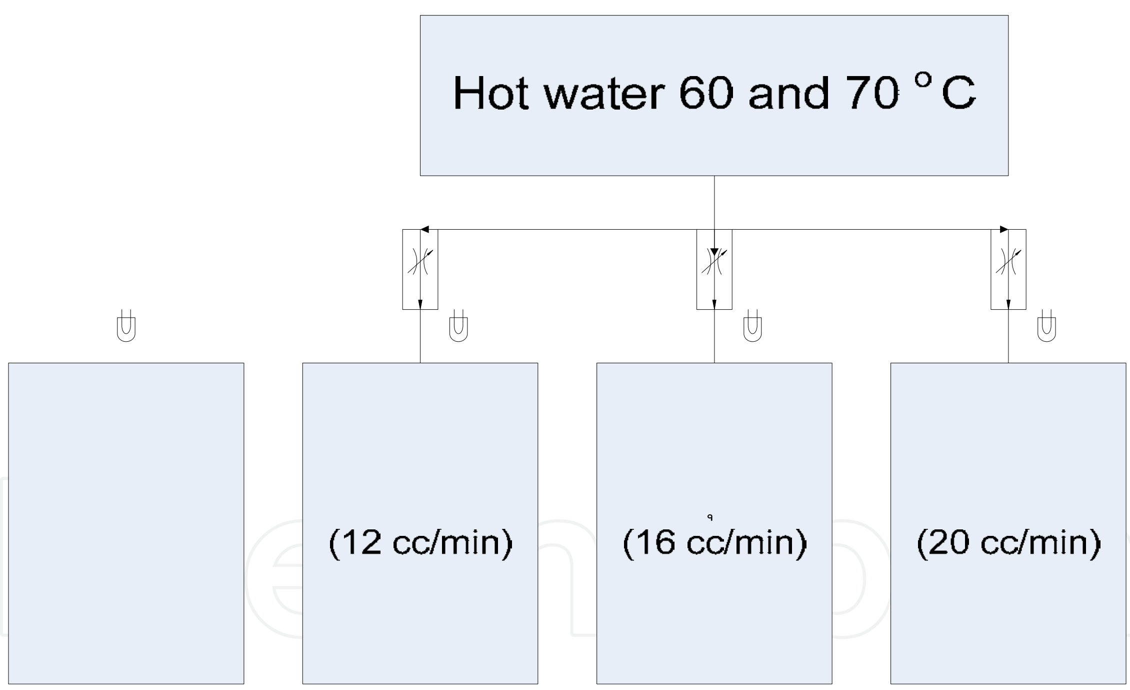


Fig. 8. Schematic diagram of hot water system for soil solarization (Phitthayaratchasak et al., 2009).

A further step to increase the efficiency of the heating process is to use copper tubes, with the surface cut into a semicircle in order to increase larger spaces to absorb the heat, and fix them at the back side of the ACPC panel as shown in Fig. 9. The temperature at various spots as shown in Figs. 10-11 was recorded every 5 min continuously for 5 h. There was no water dropping during the first 30 min and the last 90 min. The same water dropping process was repeated using the 70°C hot water (boiler).

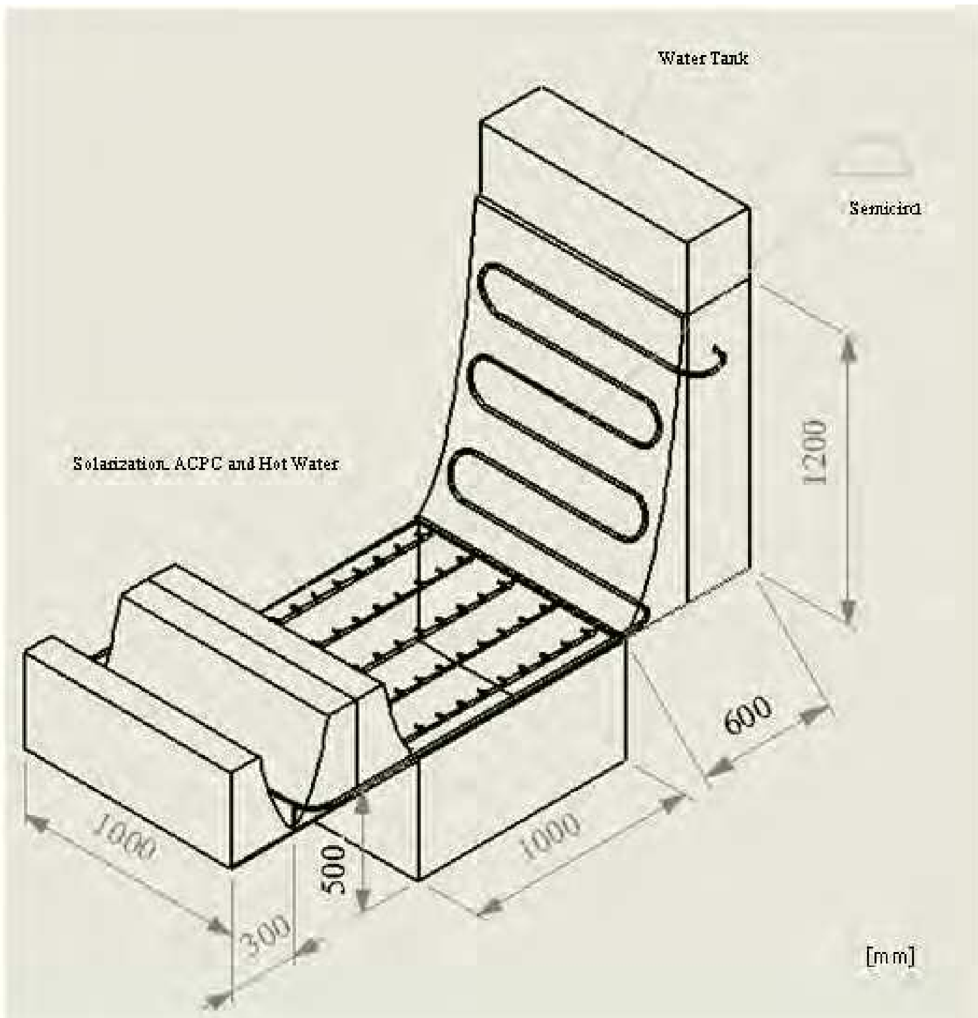


Fig. 9. Installation of combined CPC and ACPC soil solarization system.

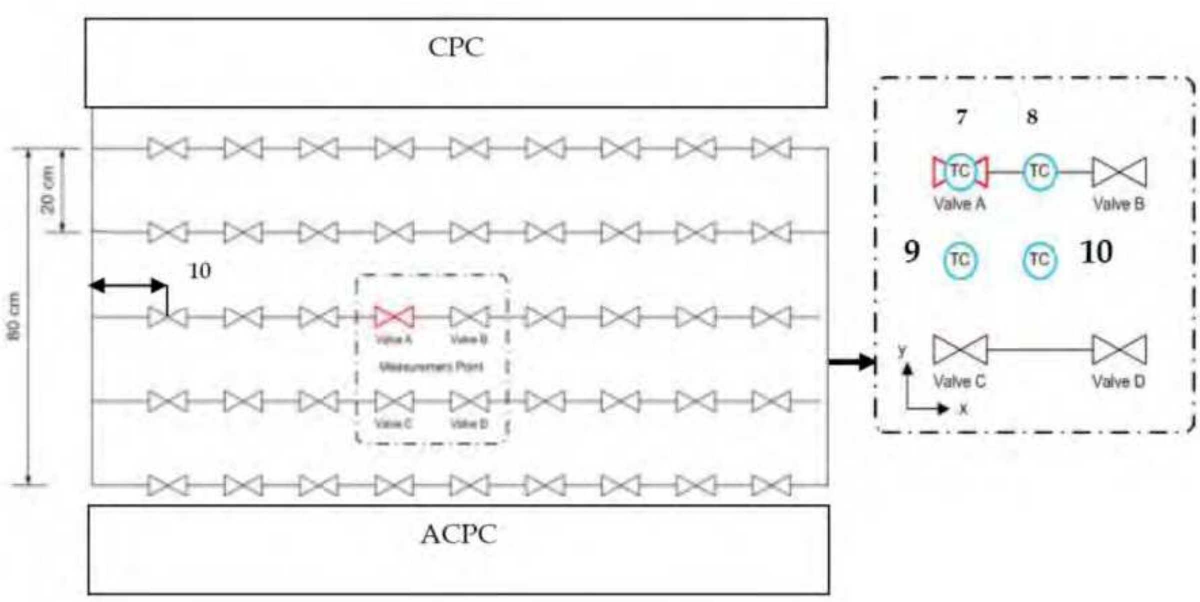


Fig. 10. Positioning of hot water nozzles and thermocouple

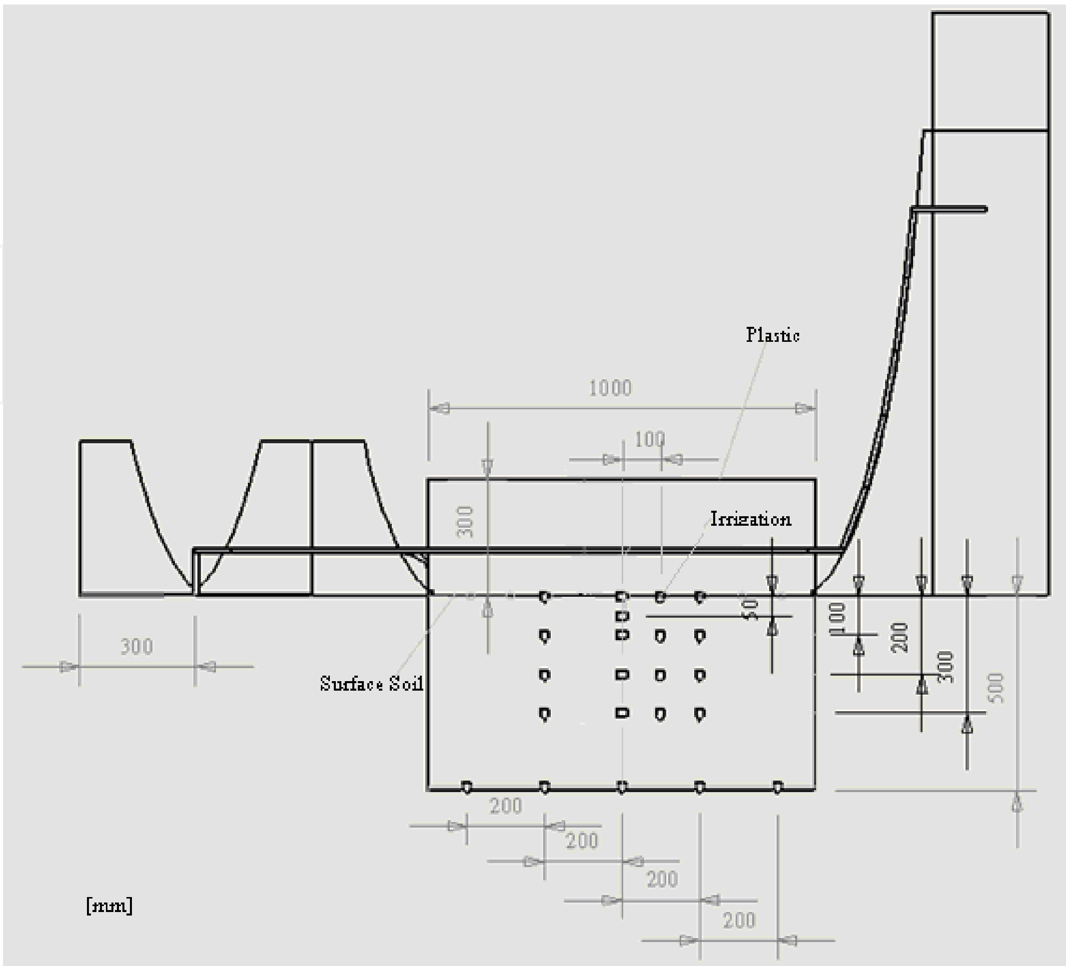


Fig. 11. Side-view of test apparatus setup showing positions of hot water nozzles and thermocouples

3.4 Effect of the treatments on soil microorganisms

Bacterial suspension containing 4×10^7 cfu/ml prepared from culture of E. cartoverora strains were mixed thoroughly with sterile soil. After heat treatment by non-solarization, solarization, solarization with ACPC, solarization and CPC combined with ACPC and hot water during 12.30 to 16.30 hour for 0, 1, 2 and 4 h incubation at soil surface and the soil at 5-20 cm depth, the soils were counted for Erwinia spp. growing on culture medium compared to the control (non-solarization).

3.5 Bacterial treatment

Bacterial suspension of *E. cartoverora* strains were mixed thoroughly with soil. The first set where the sterile soil mixed with *E. cartoverora* suspension in sterile bags were placed at soil surface soil, soil 5 cm, 10 cm, and 20 cm depth in non-solarization plot. The second set where the soil was mixed with bacterial suspension of *E. cartoverora* strain and placed at soil surface, soil 5 cm, 10 cm, and 20 cm depth in solarization plot. The third set where the soil was mixed with bacterial suspension of *E. cartoverora* strain and placed at soil surface, soil 5 cm, 10 cm and 20 cm depth in solarization with ACPC plot. The fourth set where the soil was mixed with bacterial suspension of *E. cartoverora* strain and placed at soil surface, soil 5 cm, 10 cm and 20 cm depth in solarization with ACPC and hot water plot.

3.6 Plant materials and growth conditions

Tomato seeds (L. esculentum Mill) were sterilized with 0.5% $HgCl_2$ for 5 min, soaked for 6 h in distilled water after being washed five times, then germinated at 25°C for 14 d in the soil containing E. cartoverora with the solarization with ACPC treatment and control in Erlenmeyer flask. Seeds of tomato were sown in sterile flasks, each containing sterile soil used for growth of seedlings, twenty seeds were sown in each flask at equal distances and watered as required to keep soil moist but not wet, all flasks were placed on a bench at room temperature.

3.7 Soil treatment

One millilitre bacterial suspension containing $4x10^7$ cfu prepared from an overnight culture of *E. cartoverora* strains were mixed thoroughly with each gram of soil. Four sets of flasks, each containing 4 bags, were used in this experiment. The first set where the sterile distilled water was mixed with sterile soil. The second and third sets where the soil was mixed with bacterial suspension of E. cartoverora strain and treated with solarization with ACPC and solarization with CPC combined with ACPC and hot water, respectively, before sowing. The forth set where the soil was mixed with bacterial suspension of *E. cartoverora* before sowing. Twenty seeds were sown in each bag, then watered with sterile water and maintained at room temperature. Two weeks after sowing, seedlings of each set were determined for weight and germination.

3.8 Determination of plant fresh weight and dry weight

After 14 days of planting, plant fresh weight was directly measured using an electronic scale and expressed as means of at least 20 tomato seedlings. For the determination of dry weight, samples were harvested, then dried at 105°C for 10 min, and kept at 80°C until dry weight remained constant. After cooling at room temperature, dry weights were weighed using an electronic scale.

4. Results

4.1 Thermal performances of CPC and ACPC

To evaluate the thermal performance of the concentrating system, the collectors were aligned with east-west axis. The large reflector of ACPC was oriented towards the south and a small reflector faced north. The CPC was placed next to the small reflector of the ACPC. Solar radiation at the middle point between the large and small reflectors of the ACPC, and on a normal plane outside the ACPC was measured. Fig. 12 shows the measured solar radiation.

As expected, the ACPC can increase the intensity of solar radiation within the range of 1.77 to 3.30 times during 9:30 a.m. – 5:30 p.m. and the average value is 2.5 times at 1:00 p.m. The maximum solar intensities at the measured points on a normal plane outside the ACPC and between the ACPC reflectors were 938.50 W/m² and 3097.41 W/m² respectively. The inlet and outlet temperatures of the ACPC were measured after flowing water through the collectors from 1:00 – 5:00 p.m. The surface temperature of the ACPC reflector and the CPC fin were also measured.

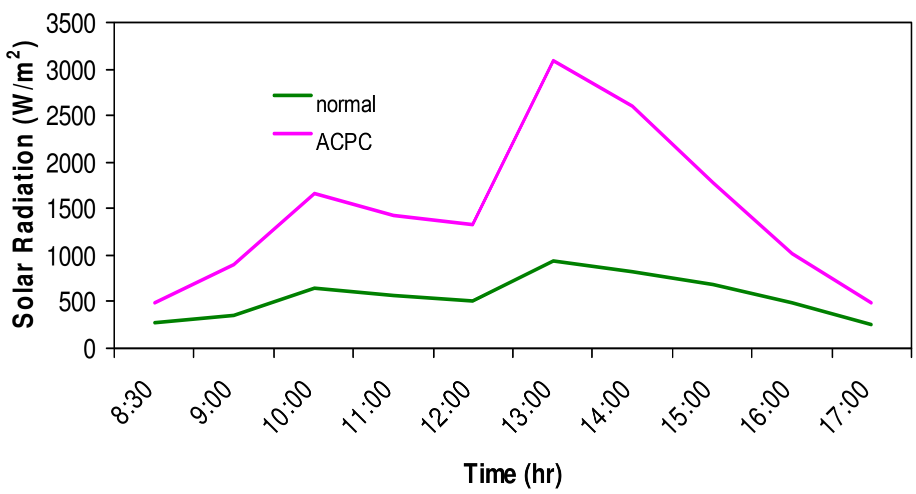


Fig. 12. Solar intensities measured at normal plane outside ACPC and between the reflectors.

Fig. 13 shows the measured inlet and outlet temperatures of ACPC and CPC during the test period in which the solar radiation was in the range of 253.99 – 938.50 W/m² with the average value of 643.8 W/m². As a result, the water temperature difference between the inlet and outlet of ACPC ranges from 4.6°C to 13°C. After passing the CPC, the water temperature was increased in the range of 1.9 - 8.4°C, additionally.

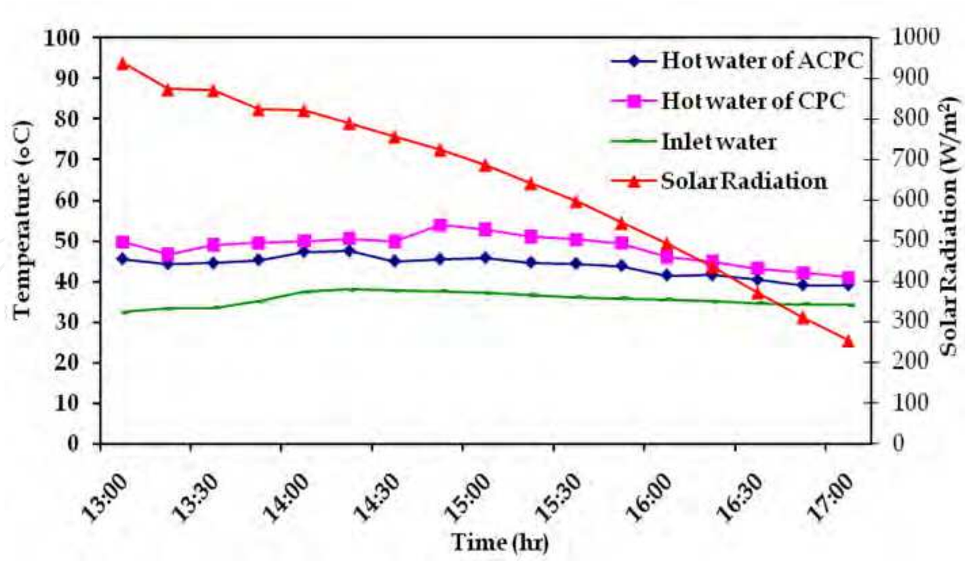


Fig. 13. Solar radiation and inlet/outlet temperature of ACPC and CPC.

Thermal efficiency of a solar thermal energy system is normally defined as the ratio of the useful heat and the incident solar energy. As shown in Fig. 13 the thermal efficiency of ACPC, based on the solar radiation in Fig. 14, is in the range of 46.42% - 51.58% (48% on average) while that of CPC ranges from 42.63% to 58.60% with 51.30% on average. It is noted that efficiency of a solar thermal system varies according to solar radiation level and environments at the time. Wind velocity is one of the key factors that influence hot water production as it increases thermal loss while flows pass a collector.

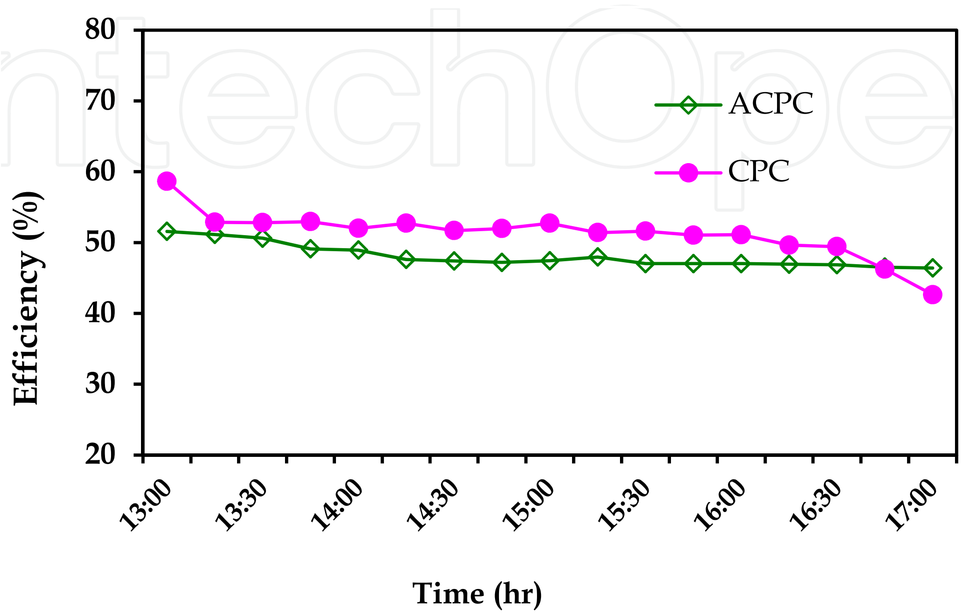


Fig. 14. Comparison of the efficiencies of CPC and ACPC.

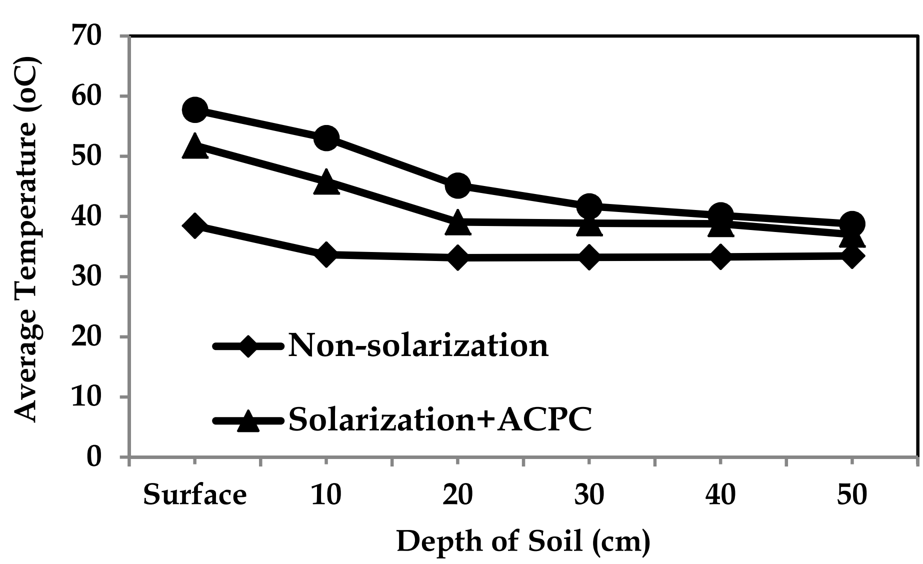


Fig. 15. Comparison of average soil temperature for all cases.

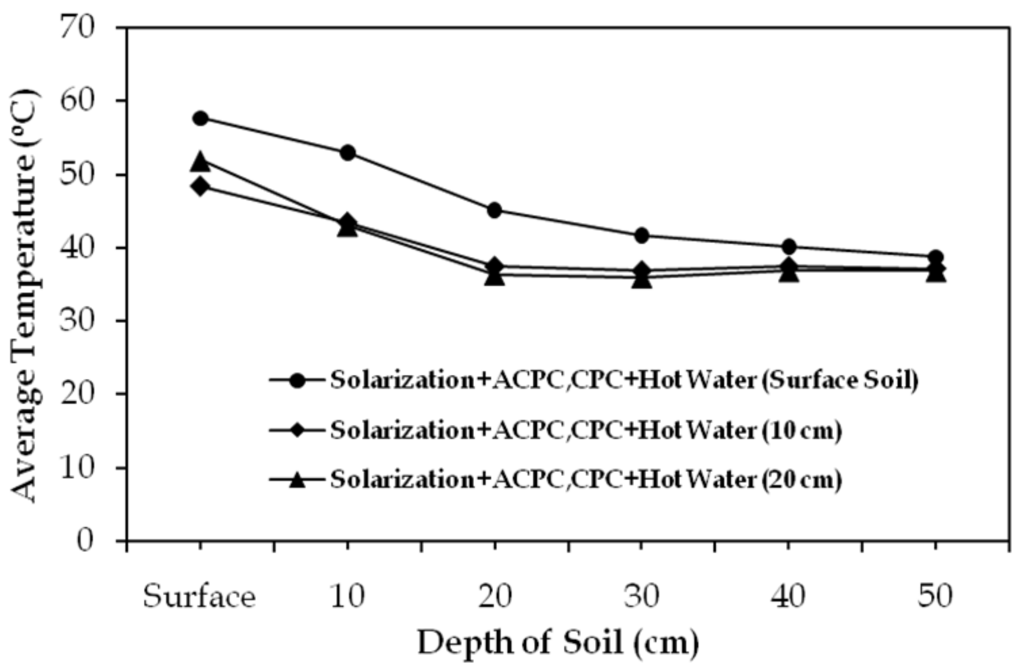


Fig. 16. Comparison of average soil temperature at various depths for the proposed case.

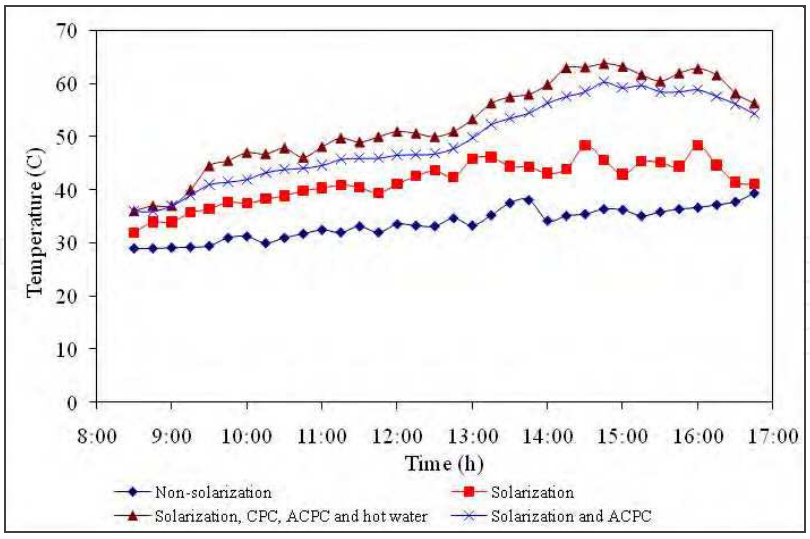
4.2 Application to reduce time to inhibit *Erwinia* in soil

4.2.1 Soil treatment

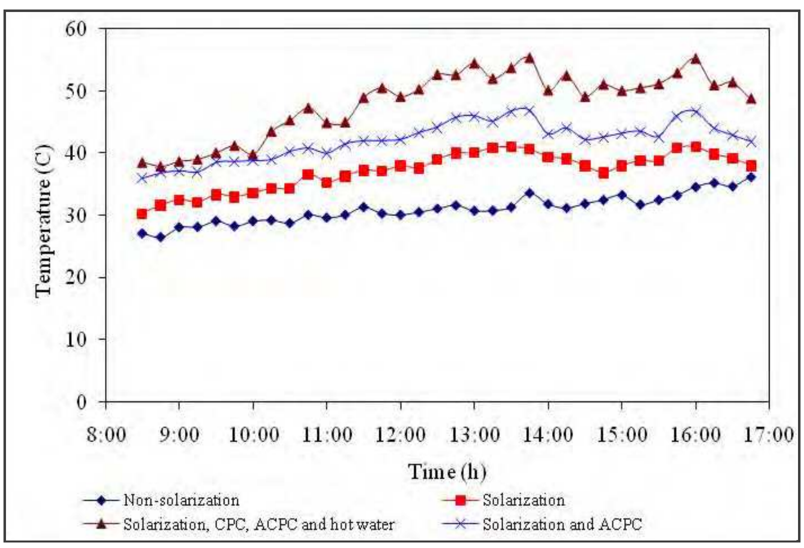
The maximum and average temperatures were always higher in solarized soil, solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil than bare soil during the experimental periods, regardless of the depth. The temperatures for non-solarized and solarized soil, solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil are shown in Fig. 17.

The temperatures for solarized ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil are shown in Fig. 17. The maximum and mean soil temperatures at 0 cm in the solarized ACPC treated soil were 60.3°C and 49.4°C, respectively. In the solarization with CPC combined with ACPC and hot water, the soil temperatures at 0 cm were 63.9°C and 52.3°C, respectively.

Table 1 shows effects of combined solar collector system of CPC and ACPC on soil surface temperature. On average, maximum surface temperature of solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil were higher than non-solarized soil. In the experiment, maximum temperature of solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil were 21°C and 24.8°C higher than non-solarized soil, respectively. The average temperature of solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil were 15.7°C and 18.9°C higher than non-solarized soil, respectively.


Temperature (C)
Time (h)
Non-solarization
Solarization
Solarization, CPC, ACPC and hot water
Solarization and ACPC

A


Temperature (C)
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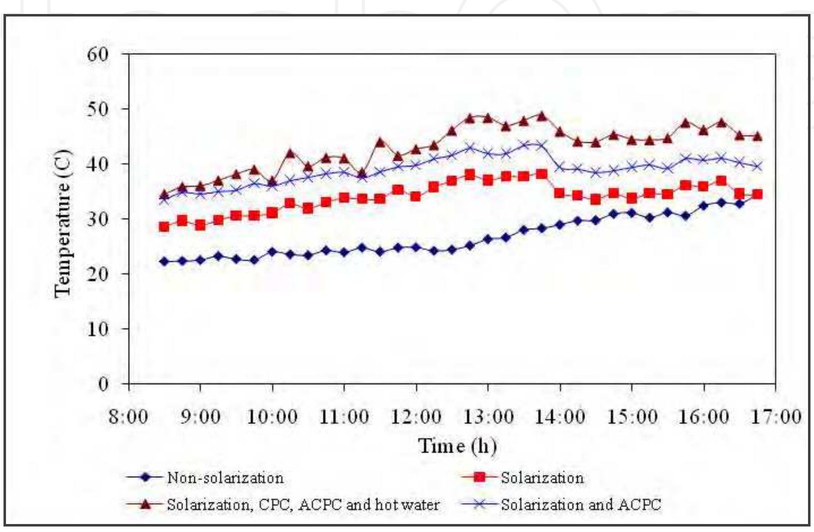
Solarization, CPC, ACPC and hot water
Solarization and ACPC

B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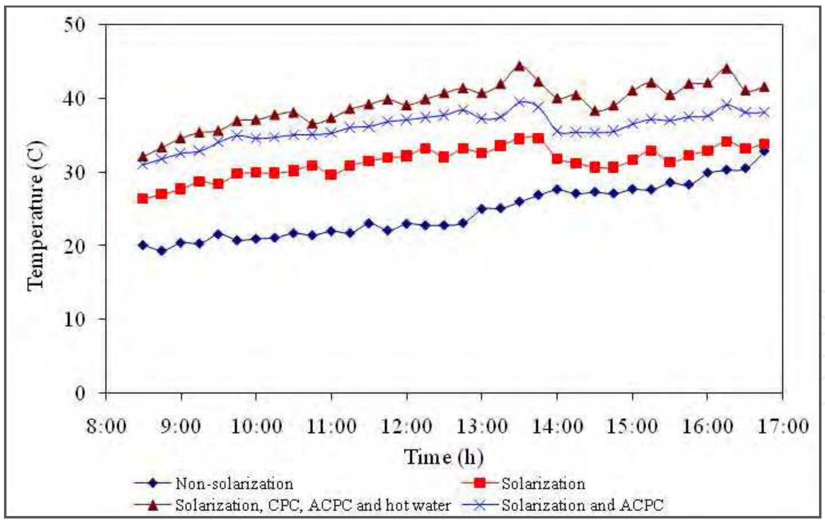

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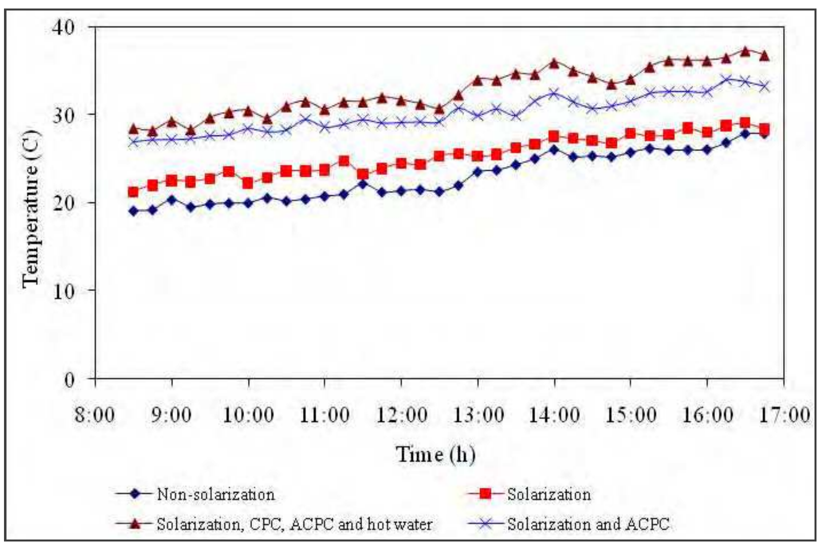

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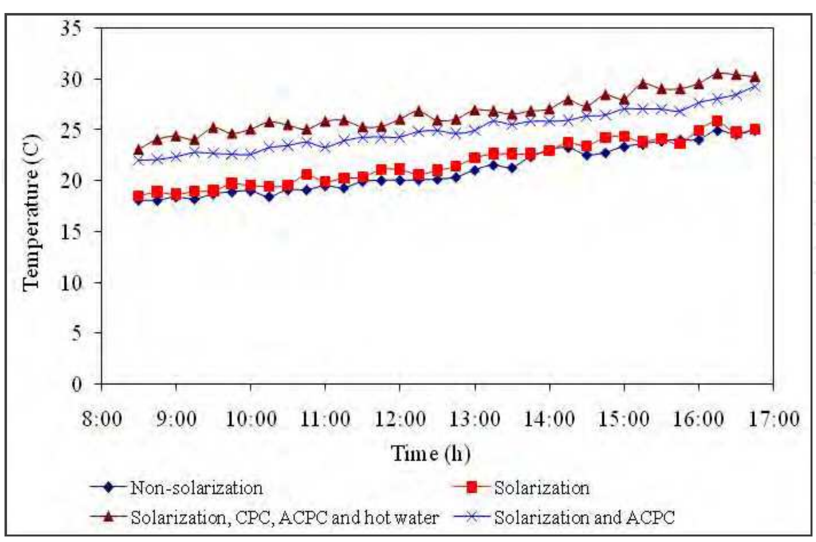

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Fig. 17. The temperature profile for non-solarized, solarized, solarized with ACPC treated and solarization with CPC combined with ACPC and hot water treated soil of (A) surface soil, (B) soil at 5 cm, (C) soil at 10 cm, (D) soil at 20 cm, (E) soil at 30 cm, (F) soil at 50 cm.

Treatment	Maximum soil surface temperature (°C)	Average soil surface temperature (°C)
Non-solarization	39.1	33.4
Solarization	42.7	38.3
Solarization and ACPC	60.3	49.4
Solarization with CPC combined with ACPC and hot water	63.9	52.3
Air temperature	36.9	32.6

Table 1. The effects of combined solar collector system of CPC and ACPC of the intensity of light of 2044.4 W/m^2 on soil surface temperature (°C).

Treatment	Soil depth (cm)				
	5	10	20	30	50
Non-solarization	36.1	34.5	32.7	27.8	24.9
Solarization	41	38.1	34.5	29.1	25.8
Solarization and ACPC	46.9	43.4	39.4	34.0	29.2
solarization with CPC combined with ACPC and hot water	55.4	48.8	44.4	37.3	30.5

Table 2. The effects of solarization with the combined solar collector system of CPC and ACPC of the intensity of light of 2044.4 W/m^2 on maximum soil temperature (°C) at 5, 10, 20, 30 and 50 cm soil depths.

The temperatures for non-solarized soil, solarized soil, and the temperatures for ACPC with solarized treated soil and solarization with CPC combined with ACPC and hot water treated soil are shown in Fig. 17. The maximum and mean soil temperatures at different soil depth are shown in Table 2 and Table 3.

Maximum soil temperatures at 5, 10, 20 and 30 cm were higher in the solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil than the non-solarized soil. The maximum soil temperatures at 50 cm for solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil were also significantly different. The maximum temperature of solarized soil was higher than non-solarized soil. In the experiment, maximum temperature of solarized soil was 4.9, 3.6, 1.8, 1.3, 0.9°C higher than non-solarized soil at 5, 10, 20, 30 and 50 cm depth, respectively (Table 2). The maximum temperature at 5 with 10, 20, 30 and 50 cm in the solarized with ACPC treated plots differed by a maximum of 10.8, 8.9, 6.7, 6.2 and 4.3°C, respectively, on any one day. The maximum temperature at 5 with 10, 20, 30 and 50 cm in the solarization with CPC combined with ACPC and hot water treated plots differed by a maximum of 19.3, 14.3, 11.7, 9.5 and 5.6°C, respectively, on any one day.

Average soil temperatures at 5, 10, 20 and 30 cm were higher in the solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil than the non-solarized soil. The average soil temperature at 50 cm for solarized with ACPC treated soil and solarization with CPC combined with ACPC and hot water treated soil was also significantly different. In the experiment, average temperature of solarized soil was 6.2, 7.2, 6.7, 2.3, 0.7°C higher than non-solarized soil at 5, 10, 20, 30 and 50 cm depth, respectively (Table 3). The average temperature at 5 with 10, 20, 30 and 50 cm in the solarized with ACPC treated plots differed by a average of 11.2, 12.2, 11.5, 7.2 and 4°C, respectively. The average temperature at 5 with 10, 20, 30 and 50 cm in the solarization with CPC combined with ACPC and hot water treated plots differed by a average of 17.2, 16.2, 14.7, 9.8 and 5.7°C, respectively.

Treatment	Soil depth (cm)				
	5	10	20	30	50
Non-solarization	30.9	26.8	24.5	23.0	21.0
Solarization	37.1	34.0	31.2	25.3	21.7
Solarization and ACPC	42.1	39.0	36.0	30.2	25.0
solarization with CPC combined with ACPC and hot water	48.1	43.0	39.2	32.8	26.7

Table 3. The effects of solarization with ACPC of the intensity of light of 2044.4 W/m^2 on average soil temperature (°C) at 5, 10, 20, 30 and 50 cm soil depths.

Soil solarization is a climate-dependent method and therefore its effectiveness in a specific region has to be assessed relative to the local climatological data. These studies that were carried out during day time showed that a combined solar system significantly increased soil temperature (Table 1-3).

Moreover, the highest increase was during when the highest temperatures were recorded, suggesting that climatological data can be used for predicting the effectiveness of combined solar collector system in a certain region. This might be related to soil temperature or the environmental factors such as the number of hours expose to sun light. Combining methods for improving pest control, especially when combining non-chemical methods, is the main objective of integrated pest management (Katan, 2000). In our studies, combining solarization with ACPC significantly improved the results in this experiment. This study thus shows that in general, the combined solar collector system of CPC and ACPC can increase soil temperature to reduce soil microbial population. However, the combined treatments of solarization and the combined solar collector system of CPC and ACPC showed a further improvement relative to the control, during which the highest temperatures were recorded. Combined methods have the potential to improve pest control but need to be optimized (Eshel et al., 2000). According to the results, the combinations increased the maximum soil temperature over the untreated control. Given the above considerations, the results illustrate the potential for combined application of ACPC with solarization, in enhancing soil surface temperature and at different soil depths for improving plant growth and in enhancing inhibition of soilborne pathogen yield. Temperature was greater at soil surface and at 5 cm depth and it gradually decreased as the soil depth increased. The maximum soil temperature treated with the combined solar collector system at 5 cm was never below 40°C after 2 hour treatment and for 5 hours it was close to 50°C.

Lower temperatures between 34.5 and 48.8°C were recorded at the 10-cm depth. At the 20-cm depth soil and 30-cm depth soil temperature fluctuated, between 29.3 and 36.4°C and between 28.5 and 37.3°C, respectively, for most of the period that soil was covered with the plastic sheets and ACPC. At the 50-cm depth soil temperature fluctuated, between 23 and 30.5°C. The temperature records in the experiment correspond to those reported by Lamberti et al. (1999). They reported that soil temperature was never below 35°C and did not exceed 40°C at 15 cm of depth of soil solarization during the summer while the following year soil temperature at the 15-cm depth was between 35 and 37°C. Higher temperature of soil solarization could be achieved by increasing the period of time exposed to the sun light considering that the temperature approaches 40°C for the treatment duration. However, in this experiment, the maximum soil temperatures treated the combined solar collector system at 5- and 10-cm depths were 48.8-55.4°C during 9 hours of the experimentation period. This level of temperature can be lethal for microorganism populations in soil. So, high temperatures during soil treated with the combined solar collector system were recorded in 5-10 –cm soil profile and these depths and therefore could inhibit soil microorganisms.

A significant observation arising from the field experiment was that the combined solar collector system for 9 hours provided satisfactory to increased high temperature. Soil solarization and the combined solar collector system resulted in high temperature at soil surface and at soil depth 5 cm over the control. In these results in combination of solarization with non-chemical control to enhance high temperature for control of microorganism wilts are in agreement with those reported for combination of solarization with non-chemical control by Giannakou (Giannakou et al., 2004), who reported that the combination of soil solarization with the bio-nematicide improved the parasite control. The parasite increased in plots compared to soil solarization and bio-nematicide plots by the end of the cropping season.

This could be partly due to the fact that soil solarization transforms soil physicochemical characteristics and partly because the combined solar collector system also has an impact on the soil microbial community. The combined solar collector system acts faster while soil solarization acts slowly, but for a prolonged period of time.

In general, it could be concluded that the novel use in the present study showed promising results by decreasing microorganism population. Soil solarization for longer time resulted in low microorganism numbers. However, more detailed field studies are required to establish the exact effects of soil solarization and on the microbial activity of soil and their impact on decreasing microorganism population efficacy.

Solarization could play a role in integrated control of different soilborne diseases but alone could not control the main soilborne diseases. Its adoption with the upgraded combined solar collector system treatment may be used to reduce the period of solarization. Solarization is mainly inconvenient by preventing use of the soil during the hot season, but possesses great potential as an alternative to fumigation for soil disinfestation. Solarization alone could control soilborne pathogens; however, the combination of soil solarization and the combined solar collector system was effective against microorganism wilts even though the solarization did not improve control of the individual pathogens. Moreover, at least in one case, the combined solar collector system increased potential of inhibition of soilborne pathogens of plants in plot area.

4.2.2 Effect of the treatments on soil microorganisms

The responses are that solarization with CPC combined with ACPC and hot water increased different temperature levels in the soil during the 4 hours in which the recorded temperatures went over 61°C, 55°C and 50°C, at 0 cm, 5 cm and 10 cm soil depth, respectively, affecting the *E. cartoverora* population (Table 4). The solarization with CPC combined with ACPC and hot water had significant effects on the microbiological population in the soil. Solarization slightly reduced the mean bacteria at 0 cm depth in 4 h about 15%. The populations of native *Erwinia* spp. in non-solarization plot at 0 cm soil treated for 4 h did not reduce significantly. After half an hour at 0-5 cm depth in the solarized with ACPC plots and solarization with CPC combined with ACPC and hot water plot the bacterial cells were reduced and after one hour the bacterial cell was undetectable. At 10 cm soil depth, the bacterial cells were reduced constantly and significantly reduced after 1 h in solarization with CPC combined with ACPC and hot water plot whereas at the 20 cm soil depth the bacterial cells were reduced constantly and significantly reduced after 2 h of treatment.

Time (h)	Population of *E. cartoverora* (cfu g^{-1})							
	Non-solarization plot (cm)				Solarization plot (cm)			
	0	5	10	20	0	5	10	20
½	2.3×10^7	1.1×10^7	3.4×10^7	2.6×10^7	1.4×10^7	2.3×10^7	2.2×10^7	2.6×10^7
1	2.1×10^7	6.4×10^7	2.3×10^7	3.2×10^7	1.6×10^6	5.2×10^7	4.7×10^7	4.4×10^7
2	3.5×10^7	1.7×10^7	4.2×10^7	5.1×10^7	1.2×10^5	2.3×10^6	5.3×10^7	2.7×10^7
4	6.4×10^7	2.2×10^7	1.6×10^7	2.4×10^7	1.4×10^5	1.6×10^6	1.9×10^7	2.9×10^7
Time (h)	Population of *E. cartoverora* (cfu g^{-1})							
	Solarization with ACPC plot (cm)				Solarization with CPC combined with ACPC and hot water plot (cm)			
	0	5	10	20	0	5	10	20
½	1.7×10^6	1.4×10^6	6.2×10^7	5.7×10^7	4.7×10^4	3.6×10^5	1.4×10^7	2.6×10^7
1	2.4×10^5	4.6×10^5	2.4×10^7	5.1×10^7	2.1×10^2	7.4×10^3	4.5×10^6	3.4×10^7
2	5.1×10^4	6.5×10^5	4.7×10^5	1.6×10^7	0	0	2.2×10^4	7.2×10^6
4	2.7×10^2	5.2×10^3	2.1×10^5	4.3×10^7	0	0	1.5×10^3	2.1×10^5

Table 4. Population of *E. cartoverora* at testing area, at varied time periods.

4.2.3 Effect of the treatments on seedling growth

There were significantly higher dry and fresh weights of tomato plants treated by solarization with CPC combined with ACPC and hot water compared with the untreated control. Treatment at soil surface with solarization with CPC combined with ACPC and hot water for 2 hours resulted in 97.74% and 85.89% increases in dry and fresh weights of tomato, respectively, compared to the untreated control. Treatment at soil 10 cm depth by solarization with CPC combined with ACPC and hot water for 2 hours resulted in 45.25% and 39.82% increases in dry and fresh weights of tomato, respectively, compared to the untreated control (Table 5).

As in the present study, the combined solar collector system was found to increase soil temperature, but not in toxic levels as reported in other disinfestation treatments, such as fumigation, steaming, autoclaving and irradiation (Chen et al., 1991). The reductions in microbial biomass and in the number of bacteria were expected, since the soil temperatures that prevailed during the solarization and the combined solar collector system treatment were high enough to cause the death of microorganisms. The data suggest that a significantly smaller microbial population in the solarized soil compared to the non-solarized plots. Soil disinfestations usually reduce the population of several species of microorganism, although thermotolerant and antagonistic species may survive the solarization treatment (Chen et al., 1991). Reductions of microorganism populations, however, have been reported in the rhizosphere and roots of solarized plants (Gamliel and Katan. 1992). Some bacteria are highly sensitive to soil solarization, which causes a reduction in their population, but they rapidly recolonize the soil again (Katan and DeVay, 1991). The results obtained regarding the effect of soil solarization with ACPC on weeds (Table 3) corroborate those of Elmore (Elmore, 1991) and Stapleton and DeVay (1995) who have included the species *Amaranthus* spp. and *E. indica* among the ones that are susceptible to soil solarization. In addition, it was also observed a reduction in infestation by *P. oleracea* after soil solarization. The weed infestation reduction observed in the present work was expected, considering the high soil temperatures that prevailed during soil solarization treated with the combined solar system, especially in the surface layers. Our studies that were carried out during day time showed that solarization treated with the combined solar system, their effectiveness, significantly increased soil temperature and increased harvest plant fresh weight (Table 2).

This study has demonstrated disease control and yield promotion by integrating solarization with the combined solar system. The inoculum density of *Erwinia* spp. was reduced after treatment by the combined solar system. This may be important in circumstances when soil solarization alone is not effective. The significant interactions between soil solarization and the combined solar collector system occurred probably because ACPC reduced the disease in solarized areas. Solarization alone was not effective for *Erwinia* at soil surface and soil 5 cm-depth for 4 hours. In the present work solarization with ACPC had a short-term effect in the control of *Erwinia* population. The present work showed that soil solarization with the combined solar collector system was suitable option for the control of *Erwinia* population, in the short time during the day. Other beneficial effects include a great reduction in weed infestation, especially in the soil surface layers, probably due to decreases in the soil microbial population. Soil solarization and the combined solar collector system enhance their economical viability and is an environmentally safe technology. Some authors have been discouraged with respect to the potential benefits of irradiation disinfection systems since they found that the efficient removal of pathogens required high energy levels (Mavrogianopoulos et al., 2000). Increases in soil temperature in the plot caused a decrease in *Erwinia* viability. *Erwinia* readily decayed and lost viability when exposed for short periods under solarization and the combined solar collector system at temperatures above 40°C. Among the solarization and the combined solar collector systems tested, treatment at soil surface with solarization and the combined solar collector system showed the most beneficial characteristics, as it consistently suppressed the *Erwinia cartoverora* and also promoted increased plant fresh and dry weight compared to untreated control (Table 2). The use of treatment at solarization and the combined solar collector system for increasing yield and for crop protection is an attractive approach in the modern system in developing a sustainable agriculture.

Treatment		Dry weight (g)	Percent increase	Fresh weight (g)	Percent increase
Time (h)	Depth (cm)				
0	0	0.442	0.00	5.017	0.00
½	0	0.587	32.81	5.975	19.09
1	0	0.826	86.88	9.22	83.77
2	0	0.874	97.74	9.326	85.89
0	5	0.442	0.00	5.017	0.00
½	5	0.594	34.39	6.172	23.02
1	5	0.796	80.09	8.428	67.99
2	5	0.847	91.63	8.952	78.43
0	10	0.442	0.000	5.017	0.000
½	10	0.494	11.77	5.297	5.58
1	10	0.573	29.64	6.474	29.04
2	10	0.642	45.25	7.015	39.82

Table 5. Effect of solarization with CPC combined with ACPC and hot water treated soil on tomato growth response (as dry and fresh weight) as compared to untreated control.

The effects of high sub-lethal temperatures are influential in reducing *Erwinia*. During day time solarization and the combined solar collector system treatment were effective in reducing *Erwinia* viability as the *Erwinia* were subjected to sub-lethal temperatures. Soil solarization and the combined solar collector system reduced *Erwinia* viability by 49.74-89.22%. Reducing *Erwinia* viability in the top 5 cm of the soil would therefore ease disease pressure in tomato crops. This study thus shows that in general, solarization and the combined solar collector system can increase soil temperature to reduce *Erwinia* in the soil and increase dry and fresh weight of plant. While the effects would not be as great deeper in the soil, the *Erwinia* may still be weakened. The use of soil solarization to control crops will be most suited to the plant growing regions. Trials are now required to determine the actual reduction in plant afforded by this technique in the field. The combination of soil solarization with combined solar collector system may provide more effective control of crops than the use of soil solarization alone.

The present investigation confirmed the feasibility of controlling *E. cartoverora* in potato growth by heat treatment by combined solar collector system of propagation material. Critical time-temperature combinations were identified which resulted in a complete inactivation of the internal bacterial population. Therefore, the heat treatments by combined solar collector methods employed were chosen to provide a gentler form of heat to control growth of soilborne pathogen.

5. Conclusion

In the experimental approach it was attempted to use CPC combined with ACPC to increase water temperature for soil disinfection and disinfestation. The system had great effects on the microbiological population in the soil with higher heat transfer at deeper soil level and resulting high yield of plant growth, with the advantage that it is compatible for a more sustainable agriculture practice. The population of *E. cartoverora* was negative correlation of time course of solarization with CPC combined with ACPC and hot water treatment while increasing of tomato seedlings weight was positive correlation with the time course of the treatment. The experiments carried out in real scale showed that the system presents numerous advantages and pollution-free environment. Relatively high initial soil temperatures can be achieved. In this way, the use of the solar system for a short time to complement the CPC with ACPC application could reduce the energy required for soil disinfestation. Increase in the soil temperature by using low cost and environment friendly renewable energies for a short time period decrease the energy demand and could make the system economically affordable for soil disinfestation.

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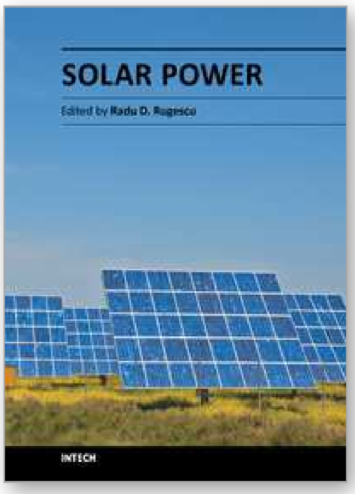

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A wide variety of detail regarding genuine and proprietary research from distinguished authors is presented, ranging from new means of evaluation of the local solar irradiance to the manufacturing technology of photovoltaic cells. Also included is the topic of biotechnology based on solar energy and electricity generation onboard space vehicles in an optimised manner with possible transfer to the Earth. The graphical material supports the presentation, transforming the reading into a pleasant and instructive labor for any interested specialist or student.