Study on Effective Soil Management Methods and Irrigation Water Requirements in the Glasshouse Cultivation

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（ハウス栽培における効果的な土壌管理方法と栽培管理用水量の検討）

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SUMMARY

Soil is linked to everything around us and plays many important roles in sustaining life on Earth. And soil provides much food that humans consuming. But only 25 % of the earth's surface is made up of soil, and among it, only 10 % can be used to grow crop. And at the same time, facing more and more soil problems, and increasing food needs all over the world, it is necessary to take appropriate measures to resolve it. So in this study, two important soil problems, soil salinization and soil-borne diseases, were investigated from the following two topics:

1. Experimental evaluation of irrigation methods for soil desalinization
2. Study on Irrigation Water Requirements for the Control of *Ralstonia solanacearum* via Soil Solarization in Managing Tomato Cultivation

In the first research, Soil salinization is a worldwide problem, particularly acute in semi-arid areas which use lots of irrigation water, are poorly drained, and never get well flushed. In order to improve the soil, there are a lot of methods, among them, the most common technique is leaching, which flush the soil with lots of water. This study was conducted in the experiment field (2 m×2.5 m) of the Gifu Universities, in order to evaluate the salt removal effect by the following four irrigation methods (flood irrigation, spray irrigation, covering irrigation, puddling irrigation), field experiment was carried out. Flood irrigation was applied at three plots with different infiltration capacities (A: 133 mm h^{-1}; B: 46 mm h^{-1}; and C: 25 mm h^{-1}). Spray irrigation, covering irrigation, and puddling irrigation were applied at the other three plots with medium infiltration capacities (D: 66 mm h^{-1}; E: 35 mm h^{-1}; F: 40mm h^{-1}). Each plot was

salinized by spraying 500 L of saline water containing 15 kg of salt, and it was dried for 3 months (from August to October in 2010). EC was measured in each plot before and after leaching experiment in order to obtain the salt content. Results showed that ① Salt removal rates of flood irrigation tended to be higher with smaller infiltration capacity, ② Compared with flood irrigation, the salt removal rate of spray irrigation, covering irrigation, and puddling irrigation were high, the salt removal effect tended to be higher with smaller irrigation intensity, ③ Irrigation intensity greatly affected the vertical distribution of salt after leaching, salt content of the surface tended to decrease with smaller irrigation intensity, was observed, ④ At covering irrigation treatment, variation of salt in the horizontal direction was small, and the most uniform salt removal effect of the four irrigation methods, which was confirmed.

In the second research, soil-borne diseases have caused extensive damage to many crops affecting the quality and yield. Soil disinfestation is a major approach to control soil-borne plant pathogens, and is especially common for high-value crops. Because of soil fumigants' negative environmental impacts, specifically as a ozone depleting substance, a new nonchemical soil disinfestation method, soil solarization are being widely pursued. In this study, 6 glasshouses (A1, A2, B~E), located at Kaizu City of Gifu prefecture in Japan, were investigated with soil solarization during the summer from 2010 to 2012. A1 and A2 belonged to the same farmer, while the other glasshouses belonged to different farmers. The cultivated crops were Momotaro J and Antelope of winter spring tomato, and the same variety have been planted in one glasshouse. In this study, many survey items were investigated, such as soil temperature, climatic conditions, temperature inside glasshouse, the effect of soil disinfestations, and the amount of irrigation water and so on. Results showed that ① The soil temperature was influenced strongly by airtight state of a glasshouse, temperature differences between inside and outside of a greenhouse, and duration and climatic conditions of the solarization period, ② The density of *R. solanacearum* decreased markedly after soil solarization with daily average soil temperature greater than 40^{o}C for consecutive 10 days or 3 days under anaerobic condition, ③ The amount of irrigation water ranged from 155.6 to 495.2 mm (average: 291.3 mm) for 2 greenhouses (A1, B) where soil solarization was effective, which corresponded to 104~346 % (average: 218 %) of the amount of water requirement from some state to become saturation state. On the other hand, the amount of irrigation water for anaerobic soil disinfection, which ranged from 218 to 247 mm (average: 231.5 mm), which corresponded to 186~188 % (average: 187 %) of the amount of water requirement. In either case, the water requirement was more than saturating the soil gap, which used as cultivation management water, was clarified.

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I Experimental Evaluation of Irrigation Methods for Soil Desalinization

1 Introduction

1.1 Background

Soil salinization is "the accumulation of soluble salts of sodium, magnesium and calcium in soil to the extent that soil fertility is severely reduced" (Tóth et al., 2008). Soil salinization is a severe problem throughout the world affecting approximately 20 % of agricultural land and 50 % of cropland in the world (Flowers and Yeo, 1995), and it is common on irrigated lands of the arid and semi-arid regions in Asia, Australia, Africa, and South America, with a variety of extents, nature, and properties (Rengasamy, 2006). In these regions evaporation exceeds precipitation greatly, salts which dissolved in the groundwater rise with the water movement, and after evaporation, accumulate at the soil surface through capillary movement (Yuan et al., 2007). Major cations in salt-affected soils are Na^+, calcium (Ca^{2+}), magnesium (Mg^{2+}), and, to a lesser extent, potassium (K^+). The major anions are chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and nitrate (NO_3^-).These soils are generally divided into three broad types: saline (EC>4 dS m^{-1}, pH<8), sodic (8.5<pH<12), and saline-sodic (EC>4 dS m^{-1}, pH<8.5). More than 120 countries are directly affected by the problem of soil salinity (AL-Khaier, 2003). Current estimates of the salt-affected soils as a percent of irrigated lands for different countries are: 27 % for India, 28 % for Pakistan, 13 % for Israel, 20 % for Australia, 15 % for China, 50 % for Iraq, and 30 % for Egypt (Stockle, 2001).

The formation of salinized soil is not only related to soil parent materials, climate, and topography, but also induced by anthropogenic activities, in particular, by improper irrigation practices. Improper quantity and quality of irrigation water and poor soil internal drainage condition often lead to soil salinization (Kitamura et al., 2006). Based on different formation reasons for soil salinization, it can divide into two categories, one is primary soil salinization, that is formed under long-term influence of various natural processes, occurring in areas where the parent material is rich in salts, a high groundwater, and the evapo-transpiration rate is much higher than the rainfall rate; the another one is human-induced secondary soil salinization, that results from human activities which change the hydrologic balance of the soil between water applied and water used by plants. Excessive amounts of salt have adverse effects on soil physical and chemical properties, soil microbial and biogeochemical activities, and plant growth (Keren, 2000; Yu et al., 2011). The effect of soil salinization on plants can express mainly in three aspects: osmotic effect (normal conditions: movement of water from a lower salt concentration outside the plant to a higher salt concentration in the plant), nutritional imbalance, toxic effect (Bastías et al., 2010; Li et al., 2010). Tejada and Gonzalez (2005) demonstrated that an increase in electrical conductivity has adverse effects on soil structural stability, bulk density, and permeability.

Saline soil reclamation is one of the major environmental challenges for humans (Szabolcs, 1994). Numerous methods have been used to ameliorate soil salinization. Now these methods are mainly divided into three kinds, as physical amelioration (leaching, drainage, soil addition, deep ploughing), chemical amelioration (the application of various soil conditioner: gypsum ($CaSO_4 \cdot 2H_2O$), calcium chloride ($CaCl_2 \cdot 2H_2O$), sulphuric acid (H_2SO_4), calcium sulphate ($CaSO_4$)), biological amelioration (organic manure, crop rotation, growing of salt-tolerant crops) (Raychev et al., 2001, Shahid Shabbir, 2002, Qadir et al., 2007, Mokoi and Verplancke, 2010). The common technique for improvement and management of saline soils is leaching, that is, a process of dissolving and transporting salt by the downward movement of water through the soil (Richards, 1954; Okuda and Onishi, 2012). Among leaching methods, flood irrigation is commonly applied in agricultural land. There are, however, several shortcomings in the method. First, the application is limited in arid and semi-arid area because the practice requires a large amount of water. Second, it is suggested that flood irrigation cannot remove salt uniformly through soil layers (Chen et al., 2002). Several studies proposed new irrigation methods for soil leaching such as drip irrigation, horizontal flushing (Qadir et al., 1998), and puddling irrigation (Häfeleet al., 1999). However, conclusive analysis of leaching efficiencies of different irrigation methods is yet to be done.

1.2 Research Objectives

In this study, a field experiment was conducted in order to evaluate leaching efficiencies of four irrigation methods, flood irrigation, spray irrigation, flood irrigation with covering sheet, and puddling irrigation. Specifically this study tested the three hypotheses:

1) Salt removal efficiency is lower for soil with higher infiltration capacity because of the short residence time of water,

2) Spray irrigation is more efficient in removing salt because of the slow infiltration rate,

3) Puddling irrigation and flood irrigation with covering sheet remove salt more homogeneously than flood irrigation because they reduce horizontal variability in infiltration.

2 Materials and Methods

2.1 Study site

This study was conducted in the experimental field of Gifu University (Gifu Prefecture, Japan; 136°44'14"E, 35°27'51"N). The field was separated by concrete panels (total height: 70 cm; 20 cm above ground and 50 cm below ground) into 14 plots (2m×2.5 m, Fig 2.1 and Fig 2.2). Among the 14 plots, six plots were used for the experiment where salt was accumulated at the surface (see details below). The soil was classified as “clay loam” according to the soil texture triangle of USDA (clay: 29-36 %; slit: 14-22 %; sand: 46-53 %). Soil physical conditions were similar in all plots. Soil particle and bulk densities ranged from 2.57 g cm^{-3} to 2.76 g cm^{-3} and from1.23 g cm^{-3} to 1.53 g cm^{-3}, respectively, and gradually increased towards the lower layer in the upper 40 cm. Soil porosities (1-[bulk density]/[particle density]) ranged from 0.44 to 0.53. In advance of the leaching experiment, the infiltration capacities were obtained in all plots. The soil surface of each plot was flooded for 2 hours with local groundwater, and the infiltration capacity was estimated based on the amount of infiltration per hour. Infiltration capacities of six plots used for the experiment ranged between 25 and 133 mm h^{-1} (Fig 2.3). To accumulate salt in the surface layer, each plot was salinized by spraying 500 L of saline water containing 15 kg of salt, and it was dried for 3 months (from August to October in 2010). The experimental field was covered with vinyl sheets on rainy days (Fig 2.4-a, b, c, d). During the drying process, rainwater was unintentionally spilled onto seven plots, resulting failure of salt to be accumulated at the soil surface. Six plots were selected for the experiments from other seven plots where salt was accumulated at the surface.

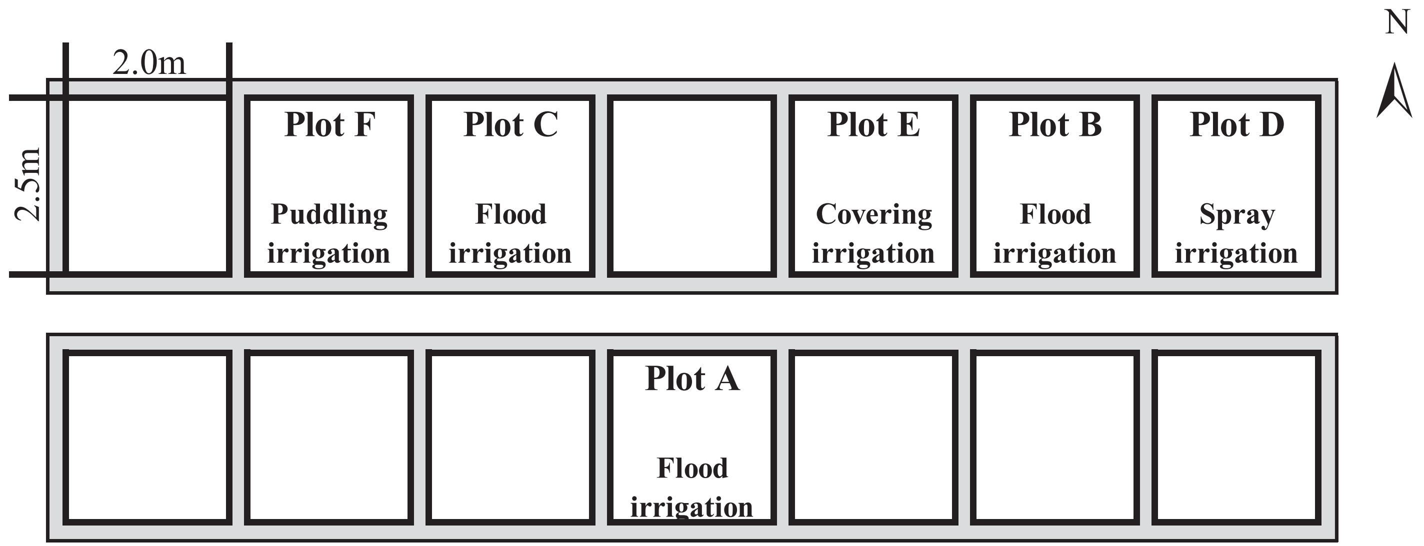


Fig 2.1 Layout of experimental plots; concrete panels (shaded area) separate the field into 14 plots (2.0 m×2.5 m); six plots (a~f) used in the experiment are marked along with the method of irrigation

Fig 2.2 The state of experimental fields

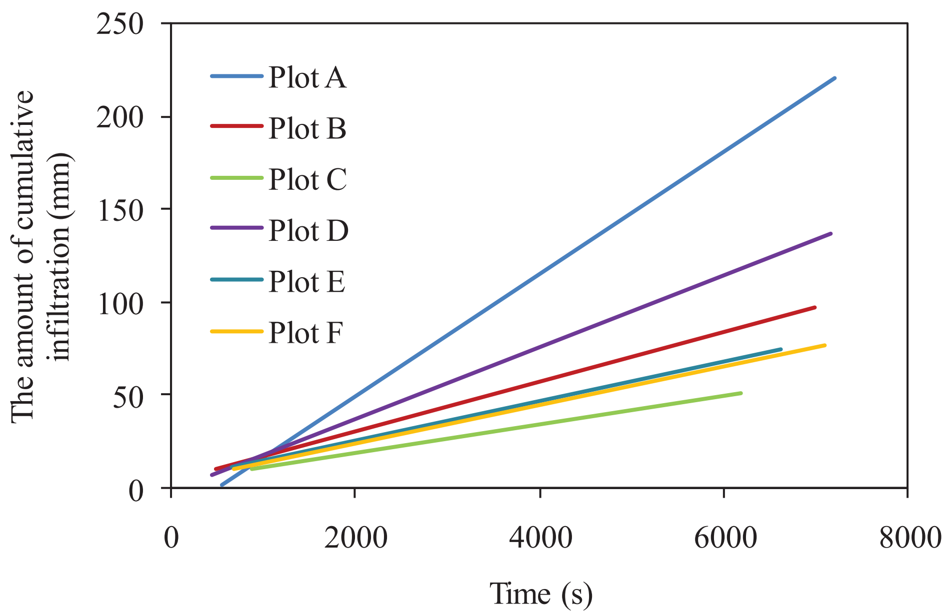


Fig 2.3 Approximate curve of infiltration capacities in 6 experimental fields

Fig 2.4-a Salt used in the experiment

Fig 2.4-b Spray saline water

Fig 2.4-c Cover vinyl sheets on rainy days

Fig 2.4-d The state of salt accumulation

2.2 Leaching methods

Four leaching methods were applied to the 6 plots. Flood irrigation was performed at 3 plots with different infiltration capacities (A: 133 mmh^{-1}; B: 46 mmh^{-1}; C: 25 mmh^{-1}) as given in Table 2.1. Spray irrigation, flood irrigation with covering sheet (hereafter, covering irrigation), and puddling irrigation were performed at other 3 plots with similar infiltration capacities (D: 66 mmh^{-1}; E: 35 mmh^{-1}; F: 40 mmh^{-1}) as given in Table 2.1. Local groundwater with negligibly small electric conductivity (EC) (<0.1 dS m^{-1}) was used for irrigation. The amount of irrigation water was 200 mm in water depth for all four leaching methods, which was approximately equivalent to the pore volume of upper 40 cm of soil layer given the porosities being around 0.5.

2.2.1 Flood irrigation

At flood irrigation treatments (A, B, and C), 1,000 L of irrigation water was flooded on the surface (5 m^2), and let the water infiltrate into the soil (Fig 2.5-a). Flooding durations were 1, 1.3, and 1.7 h, and irrigation intensities were 200, 150, and 120 mm h^{-1}, respectively in A, B, and C (Table 2.1). These values were greater than the infiltration capacities measured prior to the experiment, because cracks were developed and soil texture was altered while drying the soil for the salinization.

2.2.2 Spray irrigation

At the spray irrigation treatment (D), 5 L of water was sprayed 200 times with a watering can over 5 days (Fig 2.5-b). During the spraying process, water was applied carefully so that water did not flood on the soil surface. The irrigation intensity was estimated as 1.7 mm h^{-1} by dividing total amount of irrigation water by 5 days (Table

2.1).

2.2.3 Covering irrigation

At the covering irrigation treatment (E), the soil surface was covered by commercially available kraft paper (45 g m^{-2}) with low permeability in order to suppress the infiltration and to let water penetrate homogeneously, and 1,000 L of water was flooded on the surface (Fig 2.5-c). Flooding duration was 28 h, and hence the irrigation intensity was 7.1 mm h^{-1} (Table 2.1).

2.2.4 Puddling irrigation

At the puddling irrigation treatment (F), the surface soil (upper 5 cm) was plowed and mixed with 250 L of water to be muddy. Through this procedure, suspended soil particles precipitated and sealed cracks in soil in order to reduce rapid infiltration through cracks (Häfele et al. 1999; Haraguti 2012). Following the procedure, soil surface was flooded with the remaining 750 L of water (Fig 2.5-c). Flooding duration was 34 h and hence the irrigation intensity was 5.9 mm h^{-1} (Table 2.1).

Table 2.1 Irrigation methods, infiltration capacities estimated prior to the soil salinization, and irrigation intensities during the leaching experiment in 6 plots (A, B, C, D, E, and F)

Plot	Irrigation method	Infiltration capacity [mm h^{-1}]	Irrigation intensity [mm h^{-1}]
A		133	200
B	Flood irrigation	46	150
C		25	120
D	Spray irrigation	66	1.7
E	Covering irrigation	35	7.1
F	Puddling irrigation	40	5.9

Fig 2.5-a Flood irrigation

Fig 2.5-b Spray irrigation

Fig 2.5-c Covering irrigation

Fig 2.5-d Puddling irrigation

2.3 Soil sampling before and after leaching and measurement

Electric conductivity (EC) was measured in each plot before and after leaching experiment in order to obtain the salt content. Before the leaching experiment, salinized soil samples were collected from eight depths (0, 5, 10, 15, 20, 25, 30, and 35 cm from the surface) at four locations in each plot. After the leaching experiment, soil samples were collected from the eight depths at 16 locations in each plot (Fig 2.6-a). In the EC measurement, a soil sample (5 g dry weight) and distilled water (25 g) were mixed well in a beaker (Fig 2.6-b), and left undisturbed for 1 h. Subsequently it was mixed again and EC was determined by using an EC meter (Horiba B-173). The salt contents before and after leaching were determined from EC values by using a standard curve. EC values of standards (salinity range: 0.01-0.8 % NaCl) were measured and a standard curve was obtained:

$$\text{Salinity [\%]} = 0.0579\text{EC [dS m}^{-1}\text{]} + 0.0007 \ (R^2=0.9977). \qquad (1)$$

Using the standard curve (Eq.1, Fig 2.7), we obtained salinities of the soil-water mixtures and converted them into salt contents of the soil samples. The salt content in each 10 cm layer was computed assuming the trapezoid rule. Salt removal rates were obtained from the salt contents before and after the leaching experiment at four layers (0-10, 10-20, 20-30, and 30-40 cm) for each plot.

Salt removal efficiencies of different leaching methods were analyzed in two respects: the magnitudes and horizontal variations of salt removal. Prior to the main statistical analyses, it was checked whether there were significant differences in salt accumulation at each depth in six plots. One-way ANOVA was performed for EC values before the experiment at each depth of six plots separately (n = 4 at each depth for each plot), and no significant differences were detected. Therefore, all EC values from six plots (*n* = 24) were pooled and were considered as initial condition at each depth. In order to evaluate the magnitudes of salt removal in different plots, pairwise comparison of mean at each depth was performed separately using the Games-Howell method (Games and Howell 1976; Sokal and Rohlf 2012). In order to evaluate the horizontal variations of salt removal, coefficients of variation (CV) for EC values at each depth were compared separately using the method of Zar (2010) with the Bonferroni correction. These comparisons were made for initial EC (*n* = 24 at each depth) and EC after the leaching experiment (*n* = 16 at each depth in each plot) treating plots as a single factor. All statistical analyses were performed using the software R (The R Foundation for Statistical Computing, http://www.r-project.org).The level of significance α=0.05 was set in all analyses.

Fig 2.6-a Soil sampling

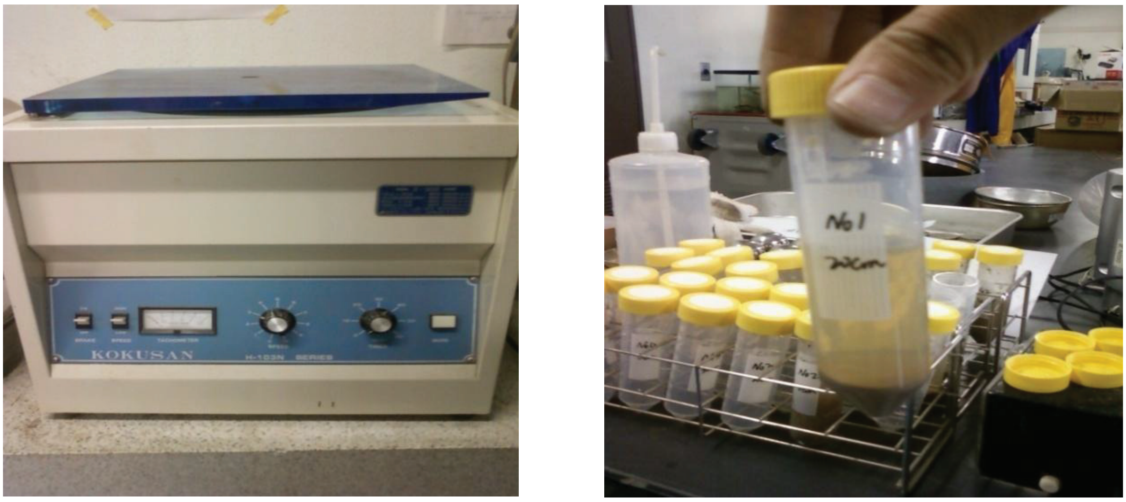


Fig 2.6-b Centrifuge and soil sample

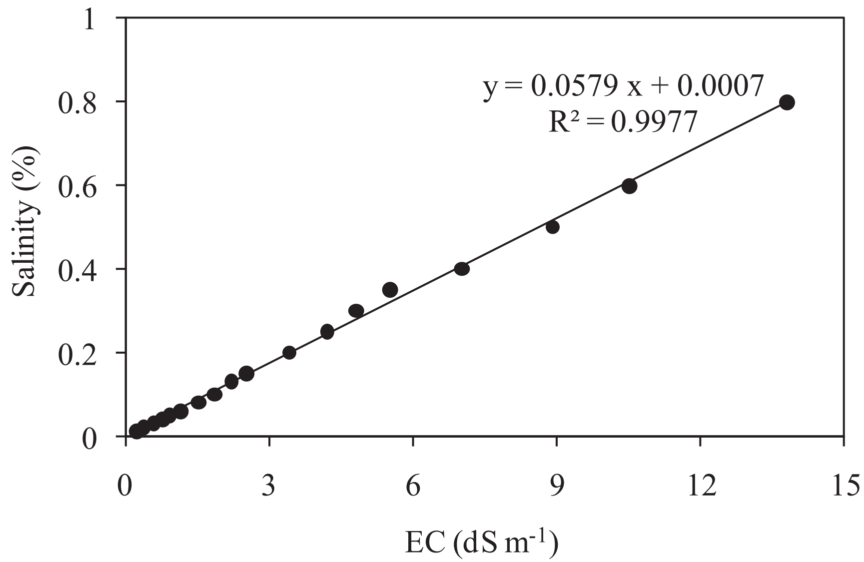


Fig 2.7 The relationship of salinity and EC by experiment (salinity range: 0.01~0.8 % NaCl)

3 Results

The initial vertical profiles of soil EC values showed a decreasing trend from the surface to deeper layers (Fig 3.1). EC values at the surface ranged from 6.10 to 11.70 dS m^{-1} with the average being 8.86 dS m^{-1}. At 5 cm and below, EC values ranged from 0.53 to 4.00 dS m^{-1} (Table 3.1). The CV values gradually increased from 16 % at the sufrace to 39 % at 35 cm (Table 3.1).

Vertical profiles of soil EC after the leaching experiment were shown in Fig 3.2. Profiles of flood irigation treatments (A, B, and C) showed a same trend where EC was the highest at the soil surface and gradually decreased toward deeper layers. The corresponding CV values ranged from 55 to 79 %, from 49 to 94 %, and from 40 to 63 % for plots A, B, and C, respectively (Table 3.1). In contrast, opposite trends were observed in other three plots where EC increased toward deeper layers (Table 3.1). The corresponding CV values ranged from 21 to 44 %, from 5 to 45 %, and from 35 to 88 % for plots D, E, and F, respectively (Table 3.1).

Statistical results showed significant decreases of EC from initial condition in all treatments at all depths with a couple of exceptions (i.e., at 35 cm of plot E and F; Table 3.1). Differences in EC were not significant among the flood irrigation treatments (A, B, and C) at all depths, although the mean EC values were relatively greater in plots with higher irrigation intensity at 0 and 5 cm depths (A > B > C; Table 3.1). These results did not support first hypothesis that salt removal efficiency is lower for soil with higher infiltration capacity. Yet observation at 0 and 5 cm depths did not contradict with the hypothesis. Comparison of EC values of plots B, D, E, and F showed significant differences among different leaching methods. At soil surface, EC value was significantly greater in plot B and significantly smaller in plot D than in other plots

(Table 3.1). This trend was consistent at depths 5 and 10 cm, where EC was the greatest in B and the smallest in D (Table 3.1). In contrast, significant differences were not much detected at deeper depths (Table 3.1).

Horizontal heterogeneities, evaluated by CV, significantly increased from the initial condition by flood irrigation (A, B, and C) and puddling irrigation (D) at 0, 10, 15, 20, and 25 cm, respectively (Table 3.1). This trend was also observed at other depths, although the differences were not significant (Table 3.1). In contrast, horizontal heterogeneities were significantly reduced from initial condition by covering irrigation (E) at 0 and 5 cm, and were kept at similar levels at other depths (Table 3.1). Spray irrigation (D) tended to keep horizontal heterogeneities at similar levels (Table 3.1). Among flood irrigation treatments (A, B, and C), CV values were tended to be higher in A and lower in C, although significant differences were not detected at any depths (Table 3.1). Comparison among different leaching methods showed that horizontal heterogeneities were kept at lower levels under spray irrigation (D) and covering irrigation (E), while they were at higher levels under flood irrigation (B) and puddling irrigation (F).

Salt removal rates in flood irrigation treatments ranged from 54 to 62 %, from 51 to 69 %, and 59 to 74 %, respectively in plots A, B, and C, and did not show marked vertical patterns (Table 3.2). In contrast, salt removal rates were highest at 0 cm (94, 89, and 91 %, respectively) and decreased toward the deeper layers in other three plots (34, 15, and 24 %, respectively, at 35 cm), in plots D, E, and F. Total salt removal rates correlated with the corresponding log-scaled irrigation intensity with r^2= 0.71 (Fig 3.3). This indicates irrigation intensity alone can be a good predictor of total salt removal rate.

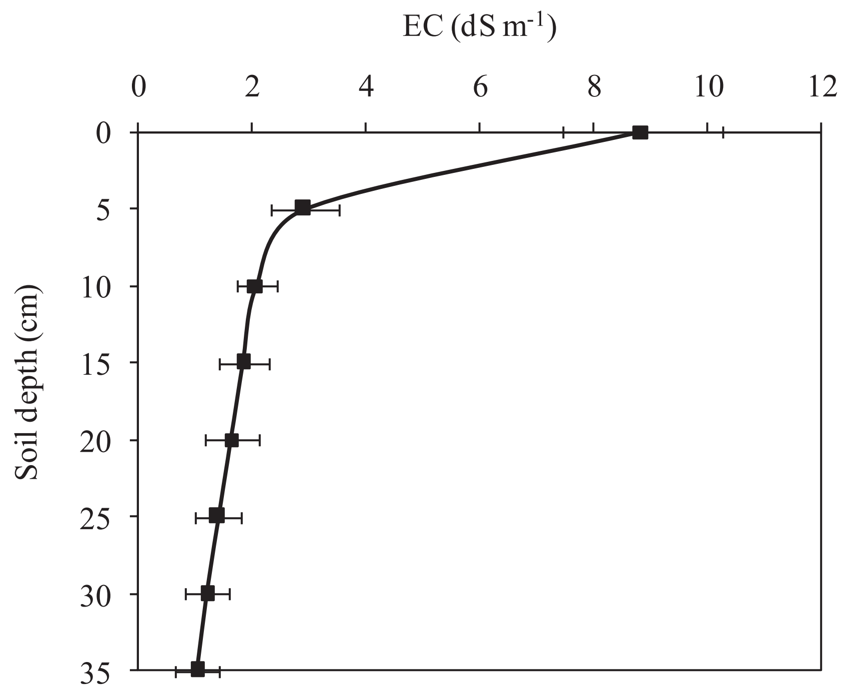


Fig 3.1 Vertical distribution of electrical conductivity (EC) averaged at each depth over six plots with the SD before the leaching experiment

Table 3.1 Electric conductivity (EC) values (dS m^{-1}) and coefficients of variation (CV) of the EC values at depths from 0 cm to 35 cm before and after the leaching experiment.

Depth (cm)	EC (dS m^{-1}) (CV)						
	Initial condition	A	B	C	D	E	F
0	8.86^{a}	2.14^{b}	1.86^{b}	1.32^{b}	0.17^{d}	0.33^{c}	0.29^{c}
	(16%^{c})	(65%^{a})	(56%^{a})	(47%^{ab})	(21%^{bc})	(5%^{d})	(35%^{b})
5	2.92^{a}	1.61^{b}	1.25^{b}	1.03^{b}	0.22^{d}	0.46^{c}	0.34^{cd}
	(20%^{c})	(70%^{a})	(49%^{ab})	(44%^{abc})	(33%^{bc})	(9%^{d})	(57%^{abc})
10	2.07^{a}	1.01^{bc}	1.06^{b}	0.83^{bc}	0.30^{d}	0.60^{bc}	0.48^{cd}
	(17%^{c})	(59%^{a})	(50%^{a})	(40%^{a})	(39%^{ab})	(27%^{bc})	(88%^{a})
15	1.84^{a}	0.77^{b}	0.90^{b}	0.69^{b}	0.42^{c}	0.68^{b}	0.66^{bc}
	(24%^{c})	(55%^{ab})	(53%^{a})	(42%^{ab})	(40%^{abc})	(37%^{bc})	(88%^{a})
20	1.63^{a}	0.61^{b}	0.72^{b}	0.56^{b}	0.49^{b}	0.76^{b}	0.71^{b}
	(29%^{b})	(60%^{a})	(57%^{a})	(48%^{a})	(36%^{ab})	(44%^{ab})	(87%^{a})
25	1.40^{a}	0.49^{bc}	0.57^{bc}	0.42^{c}	0.55^{bc}	0.77^{b}	0.75^{bc}
	(30%^{b})	(69%^{a})	(66%^{a})	(63%^{a})	(34%^{ab})	(40%^{ab})	(72%^{a})
30	1.21^{a}	0.43^{bc}	0.43^{bc}	0.36^{c}	0.60^{bc}	0.76^{b}	0.70^{bc}
	(32%^{c})	(74%^{a})	(83%^{abc})	(59%^{abc})	(39%^{abc})	(40%^{bc})	(67%^{abc})
35	1.03^{a}	0.37^{c}	0.36^{c}	0.36^{c}	0.62^{bc}	0.84^{ab}	0.71^{abc}
	(39%^{b})	(79%^{a})	(94%^{a})	(62%^{ab})	(44%^{ab})	(45%^{ab})	(56%^{ab})

Note: Different superscripts indicate that EC or CV values are significantly different in different plots within a given depth in the following order: a > b >c >d

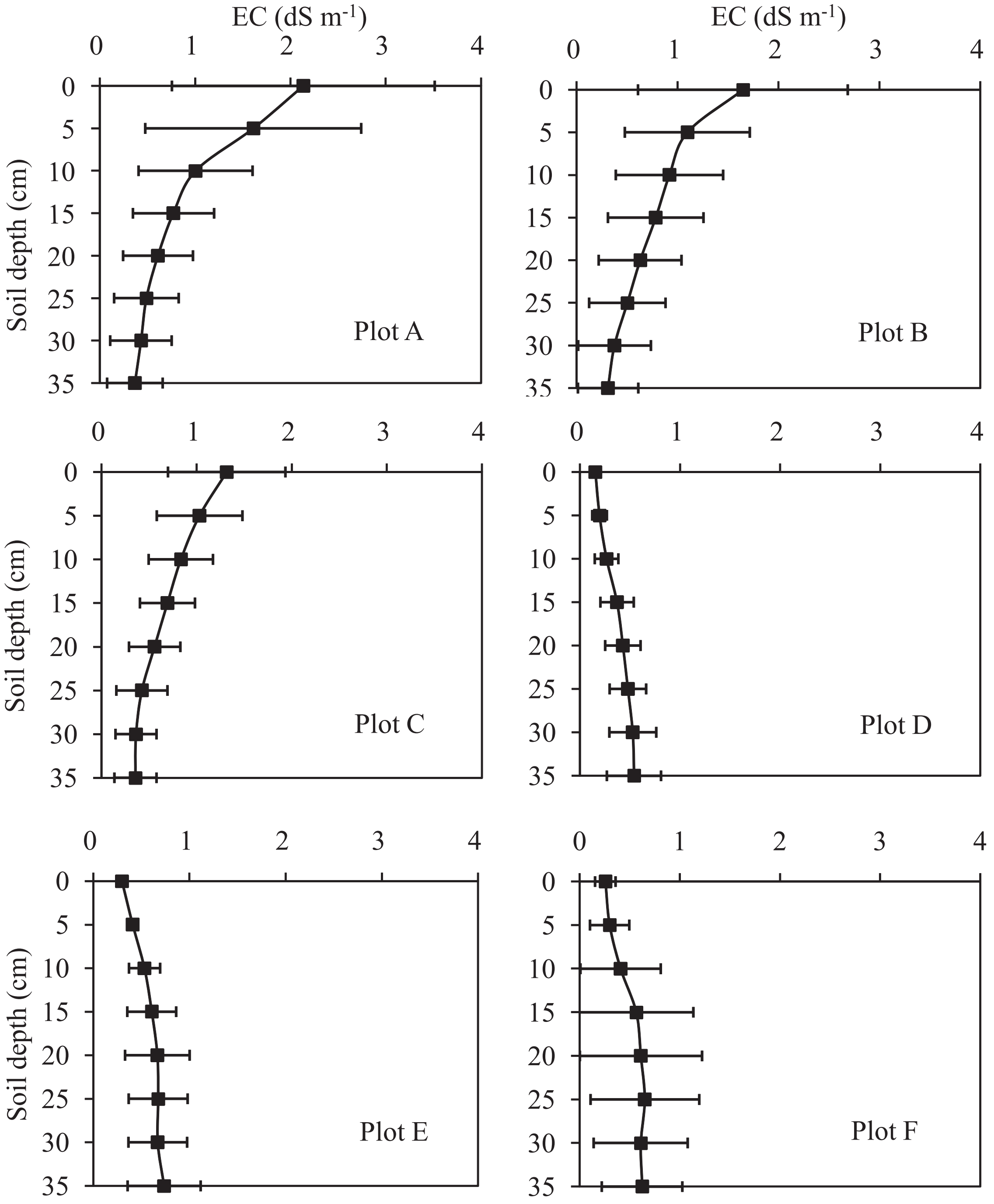


Fig 3.2 Vertical distributions of electric conductivity (EC) averaged at each depth in six plots (a~f) with the SD after the leaching experiment

Table 3.2 Initial salt content averaged over six plots, and salt content and salt removal rates of four soil layers (0-10, 10-20, 20-30, and 30-40 cm) and total soil after the leaching experiment in six plots

Soil layers (cm)	Initial salt content (kg)	Salt content (kg) (Salt removal rate)					
		A	B	C	D	E	F
0-10	15.5	6.2 (60 %)	4.8 (69 %)	4.0 (74 %)	0.9 (94 %)	1.7 (89 %)	1.4 (91 %)
10-20	7.0	3.2 (54 %)	3.4 (51 %)	2.9 (59 %)	1.6 (77 %)	2.6 (63 %)	2.4 (66 %)
20-30	5.5	2.1 (62 %)	2.3 (58 %)	1.9 (66 %)	2.2 (60 %)	3.0 (46 %)	3.1 (44 %)
30-40	4.1	1.7 (59 %)	1.5 (63 %)	1.6 (61 %)	2.7 (34 %)	3.5 (15 %)	3.1 (24 %)
Total	32.1	13.2 (59 %)	12.0 (63 %)	10.4 (68 %)	7.4 (77 %)	10.8 (66 %)	9.9 (69 %)

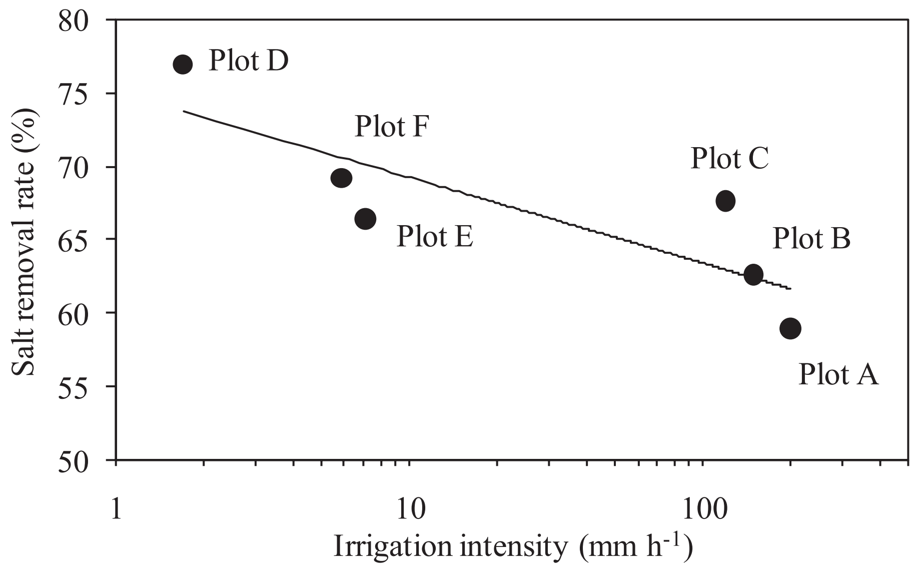


Fig 3.3 Total salt removal rate plotted against log-transformed irrigation intensity in six plots with the regression line ($r^2 = 0.71$)

4 Discussion

The present study experimentally evaluated efficiencies of various leaching methods. Specifically, three hypotheses were tested. The first hypothesis that salt removal efficiency negatively depends on the soil infiltration capacity was not supported by the present study. EC values of plots A, B, and C were not significantly different after flood irrigation though they did not contradict with the hypothesis. In the experiment, it was considered that infiltration capacities were different among the three plots from the prior measurement (Table 2.1). However, actual irrigation intensities were much greater than the capacities, probably because cracks were developed during the process of soil salinization. As a result, differences in irrigation intensities were smaller (< twofold; Table 2.1), which may not be sufficient in order to detect significant differences in EC values. This result also implies that infiltration capacity is highly variable during the course of irrigation practice and that intensity of flood irrigation is difficult to control even with prior measurements of infiltration capacity. The second hypothesis that spray irrigation is most efficient in removing salt was supported to some degree; covering irrigation and puddling irrigation were equally efficient in removing salt when compared with flood irrigation near soil surface (depth ≤ 10 cm; Table 3.1). The third hypothesis that puddling irrigation and covering irrigation remove salt uniformly at each depth was partially supported, and partially rejected. Specifically, covering irrigation significantly reduced horizontal heterogeneities at shallower depths, but puddling irrigation increased horizontal heterogeneities as much as, or occasionally more than, flood irrigation (Table 3.1). This result did not support the ideal that muddy water formed by puddling seals crack, reducing heterogeneous penetration of irrigation water. In the present experiment, puddling was applied to the salinized soil surface (~5 cm).

This may result in formation of muddy water with very high-salt concentration, which eventually penetrated through cracks to the deeper layers. Therefore, high degree of horizontal heterogeneity in soil EC was observed at depth below 10 cm (Table 3.1).

The results of the present study showed that spray irrigation was the most efficient leaching method in removing salt, and that covering irrigation was the most efficient method in reducing the horizontal heterogeneity. The practical application of these methods needs some consideration. For example, application of spray irrigation requires a relevant irrigation facility, and spatial coverage may be limited by the size of the facility. In contrast, covering irrigation is a laborsaving method that does not require specific facilities and tillage machinery unlike spray irrigation and puddling irrigation. Efficiency of covering irrigation can be further improved by selecting an optimal sheet material in order to control the irrigation intensity.

As shown in Fig 3.3, total salt removal rate negatively depends on the irrigation intensity. A study is needed to investigate how differences in irrigation intensity affect the vertical pattern of salt removal rate. Under high irrigation intensity as in flood irrigation treatments (A, B, and C), salt removal rates were similar, and the vertical variations were relatively small in each plot. In contrast, with low-irrigation intensity as in other treatments (D, E, and F), salt removal rates were highest at the surface layer, and decreased gradually with depth. Evaporation of irrigation water also needs to be considered to determine the optimal irrigation intensity. With low-irrigation intensity, more irrigation water evaporates especially under dry climate.

It could be presumed that salt removal rate depends on the volume of irrigation water, but the results of the present study indicate that the extent is related to the irrigation intensity. In Fig 4.1, we plotted salt removal rate against the ratio of the volume of irrigation water to the soil pore volume for four layers in each plot (hereafter, irrigation ratio). Interestingly, salt removal rates did not appear to be affected by increases in irrigation ratio in flood irrigation treatments (A, B, and C), where irrigation intensities were higher (> 100 mm h^{-1}; Table 2.1). On the other hand, salt removal rate increased in a saturating manner with increasing irrigation ratio in other treatments (D, E, and F), where irrigation intensities were lower (< 10 mm h^{-1}; Table 2.1). With slow infiltration of water, salt in soil is mobilized downward along with water due to the dissolution and mixing of salinized pore water and irrigation water. However, with high infiltration that exceeds the soil matrix intake rate, almost all irrigation water flows into the cracks in the topsoil by the form of the preferential flow or finger flow (Topp and Davis 1981; Kosmas et al. 1991; Mitchell and van Genuchten 1993). Irrigation intensity needs to be considerably low in order for higher irrigation ratio to be effective.

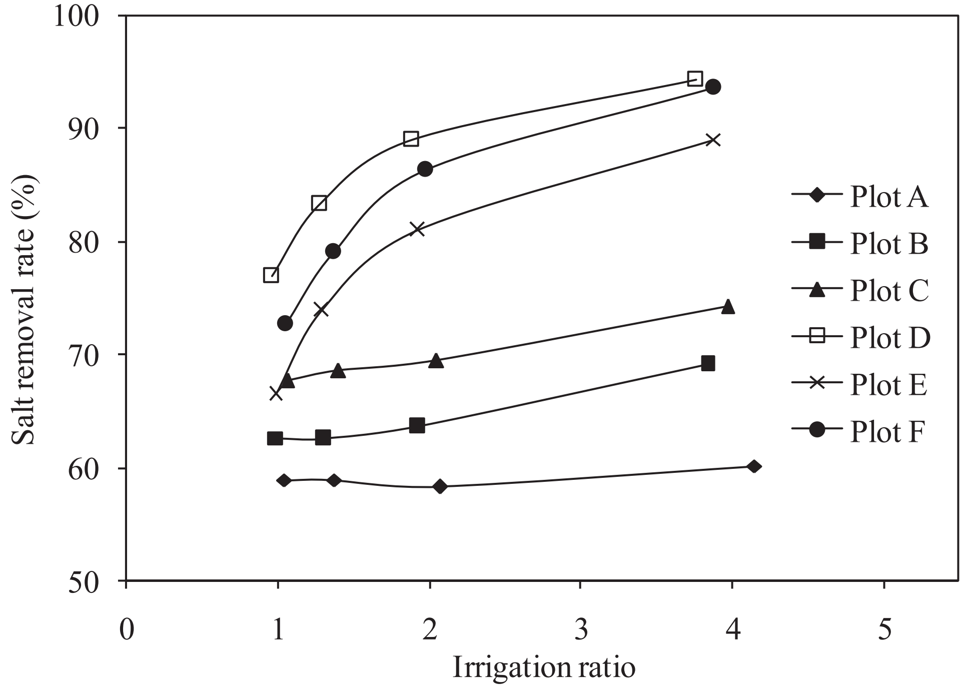


Fig 4.1 The relationships between salt removal rate and irrigation ratio (the ratio of volume of irrigation water to soil pore volume) for six plots

5 Conclusions and Recommendations

In this study, various leaching methods were evaluated experimentally. Results of the present study suggest that (1) leaching efficiency was strongly dependent on irrigation intensity (Fig 3.3), (2) irrigation intensity influences the resulting vertical distributions of salt content (Fig 3.2), and (3) paper-covered flood irrigation was the most effective in reducing horizontal heterogeneities of salt content among leaching methods (Table 3.1). Leaching efficiency may be further improved by optimizing the irrigation intensity and the water volume. For this purpose, a conclusive theoretical model would need to be developed in addition to the experimental evaluation. The present study focused on soil salinity alone. However, soil sodicity is also a major concern in arid and semi-arid regions that results in soil structural degradation and inferior plant production (Ren-gasamy and Olsson 1991; Sumner 1993). While the experiment of present study was conducted on clay soil, sandy soil is common in arid and semi-arid regions. Further investigations need to be conducted to evaluate leaching efficiency of irrigation methods in reclaiming degraded soil of various soil types.

II Study on Irrigation Water Requirements for the Control of *Ralstonia solanacearum* via Soil Solarization in Managing Tomato Cultivation

1 Introduction

1.1 Background

Tomato is a vegetable with the highest production value in Japan, in recent years, with the spread of the facility cultivation, it caused soil-borne diseases with a focus on *Ralstonia solanacearum* which were responsible to cause severe yield reduction (Fig 1.1). In the last decades, soil fumigants have been the most common approach to control soil-borne plant pathogens. Among them, methyl bromide (MeBr) has gained popularity from the 1960s. Since MeBr has the stable effect against soil-borne or low phytotoxicity to crops, it has been used on many occasions of the harvest disinfection and soil disinfection. However, methyl bromide is specified in ozone layer depletion substances under the Montreal Protocol Parties in 1992, which has been determined to phase out by 2005 in developed countries and by 2015 in developing countries (Gullino et al., 2003). The development and popularization of soil disinfection method as an alternative to methyl bromide agent has become an important issue at home and abroad (Martin, 2003). Then soil disinfection, as an eco-friendly physical control method, using by water and solar heat came to be carried out in recent years.

For previous studies of soil solarization, related to disinfection effect is in many cases, and it has been confirmed that there is a high control effect on cucumber vine wilt, peppers plague, pea blight and root-knot nematodes of cucumber-tomato (Ministry of Agriculture, Forestry and Fisheries Agricultural Research Center, ed., 1982). In addition, about soil temperature, study of thermal effect by transparent tunnel and multi has been promoted (Garofalakis et al., 2006). However, in the fact soil solarization, study example that focused on the effects of amount of irrigation and weather conditions to rise in soil temperature and bring disinfection effect (Kotane et al., 2008; Al-Kayssi et al, 1990; Al-Karaghouli and Al-Kayssi, 2001) is less, for the actual situation of the effects is not clear.

1.2 Research objective

When perform irrigation planning and evaluation and update of existing facilities, it became important to grasp the situation of water requirements in managing cultivation with soil solarization. Therefore, in this study, the amount of irrigation water, soil temperature and population density of a pathogenic bacterium *R. solanacearum* before and after soil solarization were investigated in the glasshouses which has conducted soil disinfection, in order to obtain the basic information of water requirement for the control of *R. solanacearum* via soil solarization in managing tomato cultivation.

Fig 1.1 The state of *Ralstonia solanacearum* in A2 and B glasshouses

2 Materials and methods

2.1 Soil solarization

Soil solarization (also called solar heating, plastic mulching, or soil trapping) is a method of heating the soil by covering polyethylene sheets over sufficient irrigation, to retain solar radiation during the hot season (July and August), and then kill soil-borne diseases by the high temperature and excessive moisture (Horouwitz et al., 1983; Abdallah, 1991, Fig 2.1), is a method which has less impact on the environment by not using pesticides, on humans and animals. This technology was firstly developed in Israel in the mid-1970s (Katan et al., 1976), for controlling soil-borne pathogens and weeds, mostly as a preplanting soil treatment. And it was advanced in Nara Prefecture Agricultural Experiment Station in Japan, and then because of simple and little cost, it has been popularizing already in the nation-wide scale (Kodama et al., 1980).

On the other hand, anaerobic soil disinfection is a type of soil solarization, in order to enhance the disinfection effect, mixing molasses and bran in the soil, with irrigation and covering like soil solarization, and make the soil become reduction condition by consuming oxygen through the action of microorganisms growing.

2.2 Overview of the survey field

Kaizu city of the present survey field, is located in the southernmost part of Gifu Prefecture in Japan, is sandwiched by Ibi river of the west and Kiso-Nagara river of Eastern. In this area, tomato cultivation began in 1956, acreage currently reached about 30ha, among the Gifu Prefecture, the production of winter-spring tomato is number one. And soil solarization started about 30 years ago, registered in the “Gifu clean agriculture” in 2003 (JA NiShiMino), all tomato group member made the effort to reduce the use of pesticide.

This study was conducted in 6 glasshouses, located at Kaizu city of Gifu prefecture in Japan (Fig 2.2 and Fig 2.3). The survey was conducted during the summer from 2010 to 2012. Survey was conducted in 2 glasshouses (A1, A2) in 2010, 3 glasshouses (A1, A2, B) in 2011, and 6 glasshouses (A1, A2, B~E) in 2012, A1 and A2 belong to the same farmer, while the other glasshouses belong to different farmers. Table 2.1 showed the outline of the test fields. The cultivated crops were Momotaro J and antelope of winter spring tomato, and the same variety have been planted in one glasshouse. Among 6 glasshouses, anaerobic soil disinfection was applied in A2 glasshouse and a part of A1 glasshouse (A1②). A1② glasshouse used molasses in 2012, A2 glasshouse was conducted by anaerobic soil disinfection, used molasses in 2011, and mixed bran in the soil in 2012.

Table 2.2 showed the physical properties of soil in each glasshouse. According to the soil texture triangle of USDA, the soil was mainly classified as loam (SiL) and silt loam (L), only in A2 glasshouse silt clay loam (SiCL) was seen. And soil particle and bulk densities increased toward the lower layer. In addition, as a result of the falling head permeability experiments indoor, it was revealed that the coefficient of permeability decreased toward the lower layer. All of glasshouses were converted field, low permeability layer was present in near 35 cm depth, but in B glasshouse, permeability was relatively high over the entire layer.

Fig 2.1 The state of soil solarization in test field (A1 glasshouse)

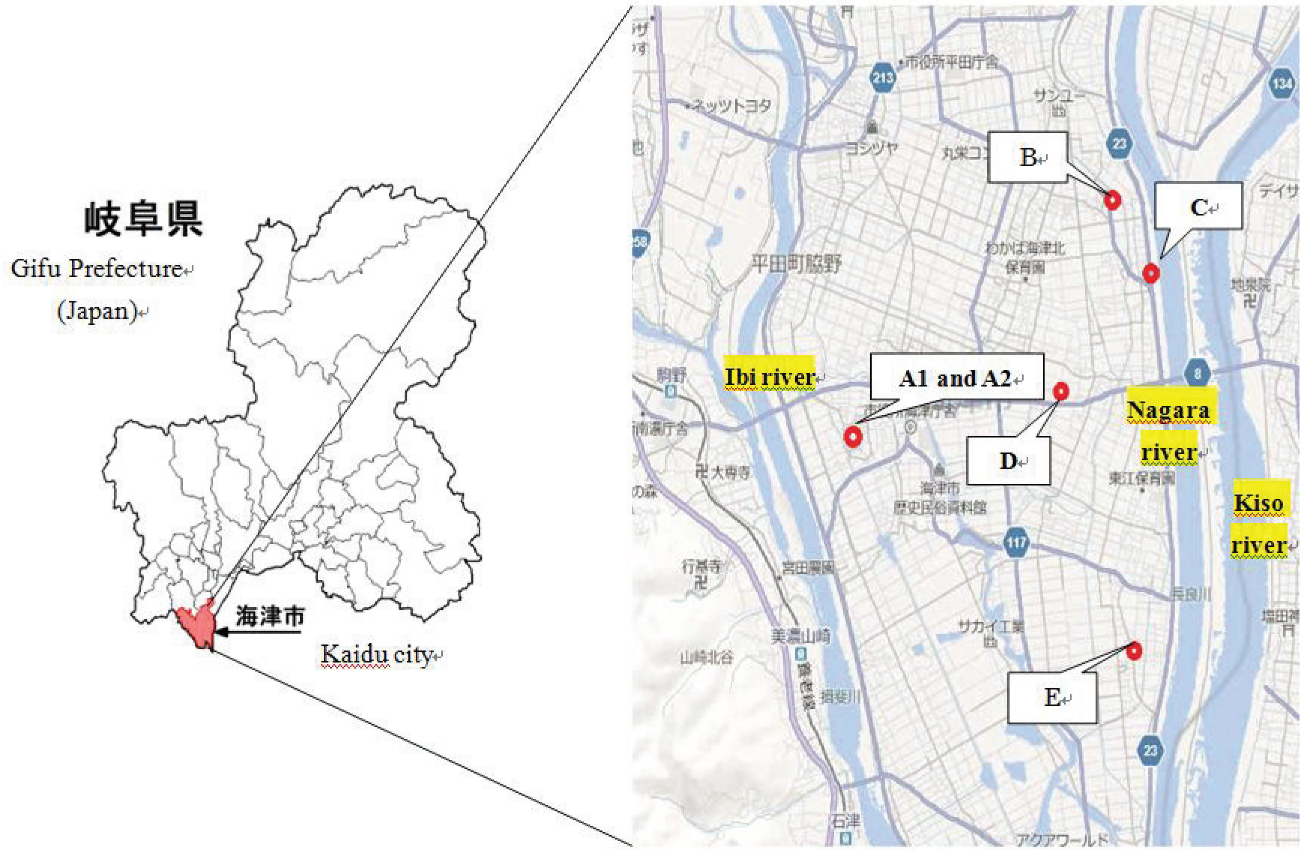


Fig 2.2 Location map of test fields

A1 glasshouse

A2 glasshouse

B glasshouse

C glasshouse

D glasshouse

E glasshouse

Fig 2.3 The situation of 6 test fields

Table 2.1 The outline of test fields

Glasshouse	Width(m)×The number of attached glasshouse×Length(m)×Height (Shoulder～Vertex) (m)	The type of glasshouse （Structure・Covering material・Direction）	Year
A1	5.5×7×35×2.0～3.2	7 attached arched roof pipe glasshouse・Agriculture PO・East and West	2010～2012
A2	10.8×3×63×2.5～4.6	3 attached even-span steel frame glasshouse・Agriculture PO・East and	2011～2012
B	10.8×3×63×2.4～4.7	3attached even-span steel frame glasshouse・Fluorine・North and South	2010～2012
C	5.4×10×48×1.9～3.0	10 attached arched roof pipe glasshouse・Agriculture PO・North and South	2012
D	4.2×10×31×3.8～5.0	10 attached arched roof steel frame glasshouse・Agriculture PO・North and	2012
E	10.8×4×36×2.7～4.7	4 attached even-span steel frame glasshouse・PET・North and South	2012

Note: Covering material: Agricultural polyolefin special film is for "Agriculture PO", Fluorine film is for "Fluorine", Polyester film is for "PET".

Table 2.2 Physical properties of soil

Glasshouse	Height (cm)	Soil texture classification	Bulk density ($g\cdot cm^{-3}$)	Soil particle density ($g\cdot cm^{-3}$)	Coefficient of permeability ($cm\cdot s^{-1}$)
A1	5	SiL	1.03	2.586	2.14×10^{-3}
	15	SiL	1.07	2.635	1.45×10^{-3}
	25	SiL	1.18	2.654	2.74×10^{-3}
	35	SiL	1.33	2.658	4.62×10^{-4}
	50	SiL	1.35	2.663	2.08×10^{-4}
	70	SiL	1.30	2.659	4.10×10^{-6}
A2	5	SiL	0.96	2.611	3.79×10^{-2}
	15	SiCL	0.98	2.649	1.65×10^{-3}
	25	SiCL	1.06	2.657	1.09×10^{-3}
	35	SiCL	1.12	2.660	4.06×10^{-5}
	50	SiL	1.28	2.683	1.90×10^{-4}
	70	SiCL	1.31	2.667	1.01×10^{-5}
B	5	L	1.02	2.595	5.73×10^{-2}
	15	L	1.13	2.641	1.73×10^{-2}
	25	SiL	1.21	2.654	1.96×10^{-3}
	35	SiL	1.36	2.655	4.72×10^{-4}
	50	L	1.40	2.661	3.33×10^{-3}
	70	L	1.57	2.658	3.50×10^{-3}
C	5	SiL	1.00	2.624	5.12×10^{-3}
	15	SiL	1.18	2.637	1.51×10^{-3}
	25	SiL	1.36	2.653	3.52×10^{-4}
	35	SiL	1.49	2.664	2.03×10^{-4}
	50	SL	1.35	2.675	1.45×10^{-3}
	70	SiL	1.34	2.671	4.13×10^{-4}
D	5	L	1.04	2.589	5.96×10^{-3}
	15	L	1.08	2.631	3.38×10^{-3}
	25	L	1.30	2.655	1.10×10^{-3}
	35	L	1.37	2.658	5.77×10^{-5}
	50	L	1.46	2.673	6.26×10^{-4}
E	5	L	1.15	2.562	1.83×10^{-2}
	15	L	1.22	2.643	1.05×10^{-2}
	25	L	1.32	2.668	7.76×10^{-3}
	35	L	1.44	2.670	3.72×10^{-4}
	50	L	1.35	2.677	2.25×10^{-3}
	70	SiL	1.28	2.674	3.08×10^{-5}

Note: "Soil texture classification" in the table is based on the soil texture triangle of USDA

2.3 Survey items

Fig 2.4 showed layout drawing of investigation equipment in test field. Soil temperature and water content were measured in one point by thermometer and TDR sensor in 5, 15, 25, 35, 50, 70 cm depth of each glasshouse. In one place of the approximate center of each glasshouse, the temperature in the glasshouse was measured at a height of 1.5 m from the field surface, and in the same place, inserted the PVC pipe to a depth of 1 m from the field surface, measured as the groundwater level used by the water level in the pipe. The measurement interval of the above items was 10 minutes. In order to grasp water requirement that was used in each glasshouse, a flow meter in the middle of the pipe from the well or water tap was installed. In addition, the meteorological data in this region referenced the AMEDAS weather data (Temperature, precipitation, daylight hours) of neighborhood Aisai city in Aichi prefecture.

Further, in order to confirm the effect of soil disinfection, soil samples were collected at two points in each glasshouse, the population density of *R. solanacearum* before and after disinfection was examined. About 10 g soil samples were collected in 5, 35, and 50 cm of each glasshouse, *R. solanacearum* was detected by culturing experiment with a TZC medium (Fig 2.5-a, b, c, d and e), a kind of selective media. At each sampling point, soil suspension was diluted by three stages of $10, 10^2, 10^3$ times with sterile water, and each stage used three plate medium. In soil disinfection period, in order to determine the redox state of the soil, the oxidation-reduction potential (Eh) was measured every 24 hours in 5 cm and 15 cm of soil solarization and anaerobic soil disinfections treatments of the glasshouse A1 in 2012. The picture of survey items are presented in Fig 2.6-a, b, c, d, e, f, g, and h.

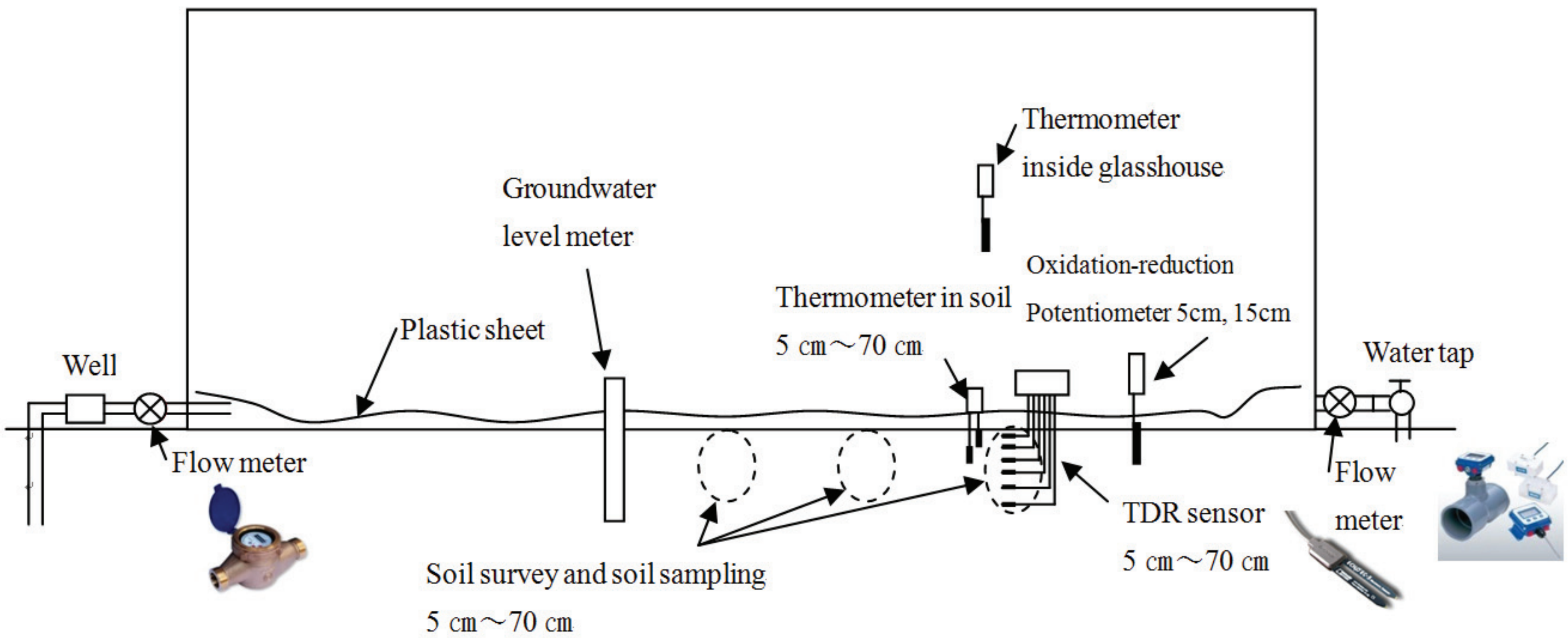


Fig 2.4 Layout drawing of investigation equipment

Fig 2.5--a Chemical for TZC medium

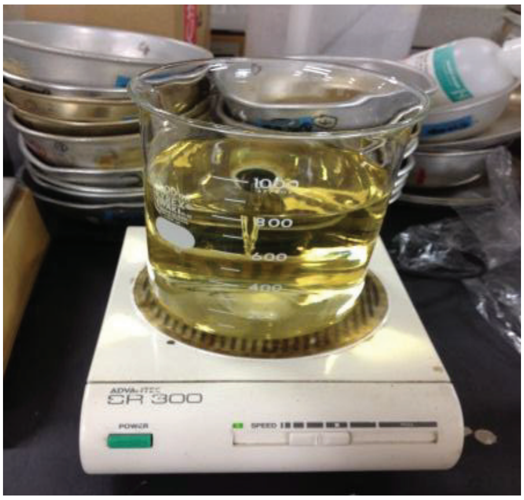


Fig 2.5-b Stirrer (agitator)

Fig 2.5-c The flasks containing agar

Fig 2.5-d The autoclave

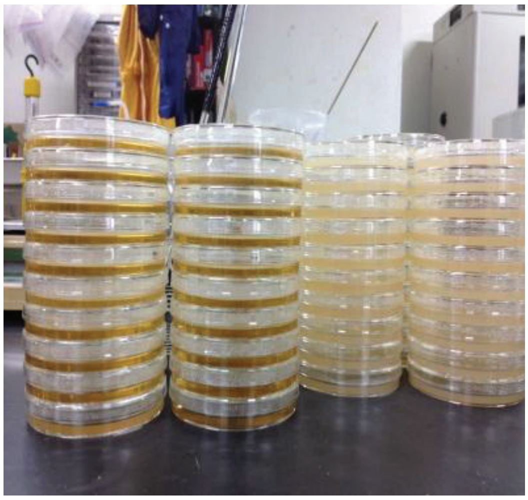


Fig 2.5-e The medium after sterilization

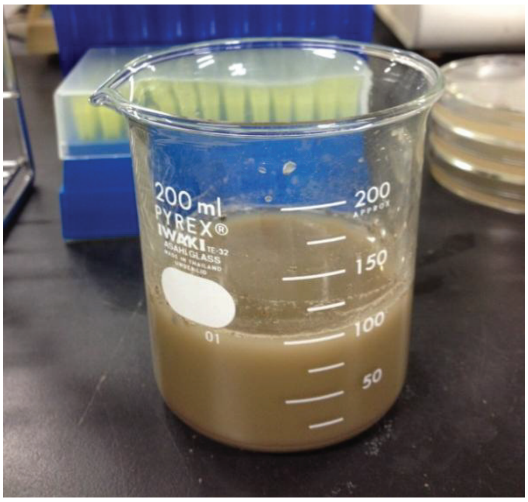


Fig 2.5-f Soil suspension

Fig 2.5-g Dilution by three stages

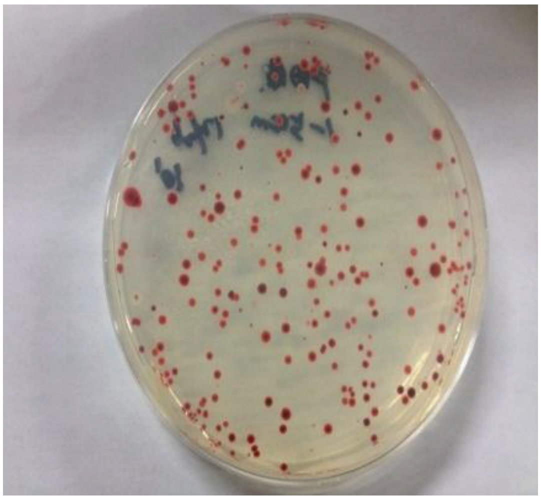


Fig 2.5-h TZC medium with *R. solanacearum*

Fig 2.6-a Thermometer and TDR Sensor

Fig 2.6-b Temperature inside glasshouse

Fig 2.6-c Oxidation-reduction potential

Fig 2.6-d Soil sampling

Fig 2.6-e Groundwater meter

Fig 2.6-f Flow meter (Water tap)

Fig 2.6-g Water meter (Well)

3 Results and Discussion

3.1 Days of solarization period and climatic conditions

Table 3.1 showed days of solarization period and climatic conditions (average outside temperature, daylight hours, the amount of solar radiation) in each glasshouse. The amount of solar radiation can be calculated from cattell time obtained from the latitude and daylight time (Ministry of Agriculture, Forestry and Fisheries Agricultural Structure Improvement Bureau, 1997). A total of 11 times soil disinfection was conducted from July 13 to September 12 with 18~33 days over 3 years in 6 glasshouses, the disinfection period of D and E glasshouse was as short as 18 days, 19 days in 2012, while A1 glasshouse was the longest 33 days in 2010. And the average period was 24 days. The average temperature outside glasshouse during disinfection period was 28.1 ℃, A2 glasshouse was lowest 26.9 ℃ in 2011, followed by C glasshouse 27.2 ℃ in 2012, disinfection period of other glasshouses was in the range of 27.9~28.8 ℃. The amount of solar radiation was in the range of 15.7~22.0 $MJ \cdot m^{-2} \cdot d^{-1}$ (average 18.2 $MJ \cdot m^{-2} \cdot d^{-1}$), A2 glasshouse was the lowest 15.7 $MJ \cdot m^{-2} \cdot d^{-1}$ during infection period.

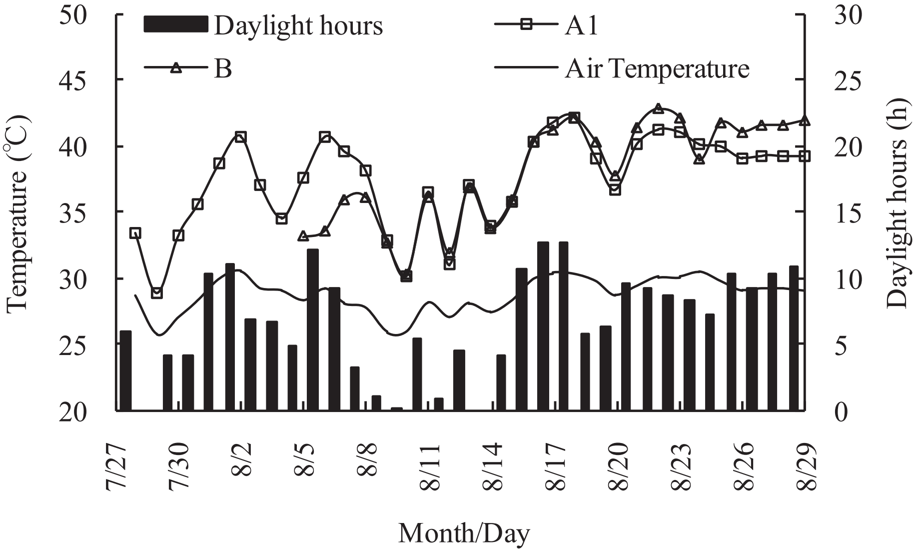
Table 3.1 Days of solarization period and climatic conditions outside glasshouse

Glasshouse	Disinfection period	Days	Average temperature (℃)	Daylight hours ($h \cdot d^{-1}$)	Amount of solar radiation ($MJ \cdot m^{-2} \cdot d^{-1}$)
A1	2010/7/28-8/29	33	28.8	6.9	17.4
	2011/ 8/1-8/24	24	28.1	6.4	16.2
	2012/ 7/29-	27	28.2	8.4	20.0
A2	2011/7/13-8/5	24	26.9	5.7	15.7
	2012/7/13-8/4	23	28.1	7.5	18.4
B	2010 /8/5-8/29	25	28.8	7.1	17.8
	2011 /7/28-	28	28.0	6.4	16.0
	2012/ 8/4-8/24	21	27.9	8.0	19.3
C	2012 /8/23-	21	27.2	6.8	17.3
D	2012 /7/24-	19	28.8	9.5	22.0
E	2012/ 7/18-8/4	18	28.3	8.4	20.3
Average	−	24	28.1	7.4	18.2

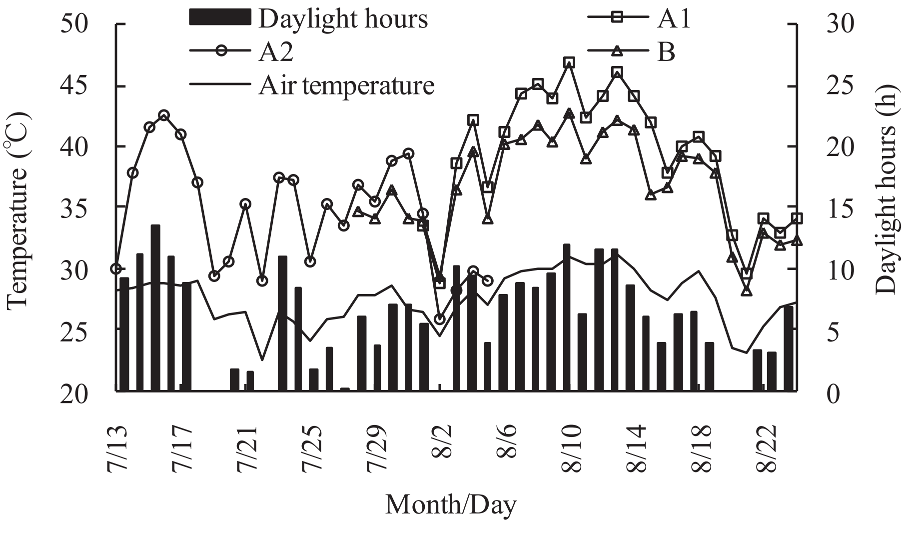
3.2 Temperature inside glasshouse

Temperature inside glasshouse varied by meteorological factors like air temperature, the amount of solar radiation, and other factors like the structure, the orientation, covering material of the glasshouse, as a closed state of glasshouse continued, temperature differences between inside and outside of a glasshouse became large (Shiroma, 1971). And temperature inside glasshouse directly related to the soil temperature, so it was considered as an important factor which greatly influences the effect of soil solarization. Fig 3.1 showed daily average temperature inside and outside glasshouse and daylight hours during soil solarization.

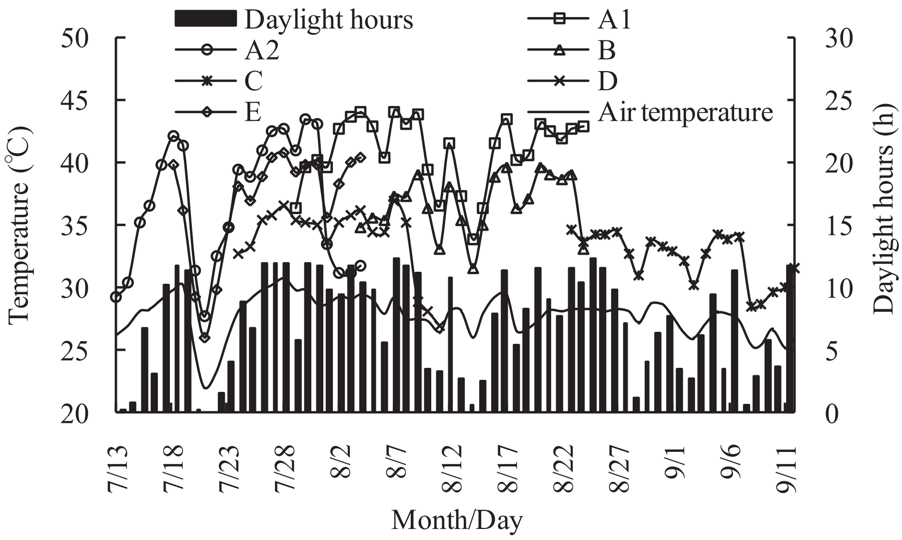
Temperature inside glasshouse was higher as compared to air temperature. The average daily temperature inside glasshouse during disinfection period rised gradually from the start of disinfection, but reduced by short daylight hours caused by rainfall and cloudy weather. When good weather days continued, it brought high temperature, then days that the average daily temperature exceeded 45 ℃ also was observed, and daytime temperature was above 55 ℃. For the maximum value of temperature differences between inside and outside of the glasshouse, 9 times of a total of 11 times soil disinfection reached more than 10 ℃ (11.7~16.4 ℃), C glasshouse and D glasshouse were 6.7 ℃, 7.9 ℃, respectively, and extremely small in comparison to the other glasshouses. There was no occurrence of *R. solanacearum* original in these two glasshouses, so farmers had little interest in soil solarization, then it resulted from the fact that airtight was not kept high caused by keeping clearance of the door and a part of the roof of the glasshouse. As a result of the above, temperature difference between inside and outside of the glasshouse became large by continuous sunny days and higher airtight state, then it has been suggested that temperature inside glasshouse can maintain a high temperature.



(a) 2010



(b) 2011



(c) 2012

Fig 3.1 Daily average temperature inside and outside glasshouse and daylight hours during solarization periods

3.3 Soil temperature

According to previous studies of soil solarization, R. solanacearum was killed with daily average soil temperature greater than 40 ℃ for consecutive 10 days (Magoko et al., 1987) or 3 days under anaerobic condition by mixing the bran and molasses into the soil (Shichon, 2003). Therefore, the standard temperature was set as 40 ℃, maximum consecutive days of daily average soil temperature reaching the standard temperature in each glasshouse was counted (Table 3.2). From this, days that the standard temperature reached, was different by different glasshouse even in the same year, also, it was different from year to year even in the same glasshouse, has been revealed.

A1 glasshouse exceeded days that the standard temperature reached to 15 cm in 2010 and 2011, and the ① in 2012 that the average daily amount of solar radiation of disinfection period was the largest, met the conditions until 25 cm depth. In addition, the ② in 2012 that soil reduction conducted, had met the death conditions of R.

solanacearum to the deeper 35 cm layer.

Soil reduction was carried out at approximately the same time of 2011 and 2012 in A2 glasshouse, death days was reduced to three days in this disinfection method, the soil temperature met this criterion to 5 cm depth in 2011, 15 cm depth in 2012.

The days that soil temperature exceeded the standard temperature was more than extinction days (10 days) for B glasshouse until 25 cm depth in 2010, and until 50 cm depth in 2011, but in 2012 it didn't meet this criteria, the days of disinfection period was more and more longer, the tendency that soil temperature increased until the deep layer

D glasshouse and E glasshouse had the days that reached the standard temperature at 15 cm, but didn't meet extinction days (10 days). Especially for C glasshouse, it didn't reach the standard temperature over the entire layer. For the reasons, temperature inside glasshouse didn't rise by bad airtight state as previously described in C and D glasshouse, disinfection period was the shortest 18 days (Table 3.1) in E glasshouse, was considered.

Table 3.2 Maximum consecutive days of daily average soil temperature reaching the standard temperature 40 in each glasshouse (days)

Glasshouse		A1				A2		B			C	D	E
Year		2010	2011	2012 ①	2012 ②*	2011*	2012*	2010	2011	2012	2012	2012	2012
Height (cm)	5	13	14	14	14	4	7	14	18	9	0	3	5
	15	11	10	13	13	1	5	13	17	8	0	1	2
	25	—	9	11	11	0	1	12	16	4	0	0	0
	35	0	7	7	7	0	0	8	14	0	0	0	0
	50	0	2	1	2	0	0	1	11	0	0	0	0
	70	0	0	0	0	0	0	0	0	0	0	0	0

Note: The shaded parts showed the days that day average soil temperature exceeded the standard temperature was more than extinction days. * showed soil reduction, 40℃ for consecutive 3 days, other ones showed soil solarization, 40℃ for consecutive 10 days.

3.4 Impact of soil reduction on soil temperature and reducing condition

Two test plots of soil solarization district (A1①) and soil reduction district (A1②) added with molasses were arranged in A1 glasshouse in 2012, then soil temperature and oxidation-reduction potential were measured. A comparison of soil temperature of soil solarization district and soil reduction district, maximum difference was 1.5℃, significant difference wasn't seen (Fig 3.2). Soil temperature rise due to fermentation heat of molasses has been expected, but it can't confirm such an effect.

On the other hand, oxidation-reduction potential (Eh) greatly reduced on the second day after irrigation (Fig 3.3) in both test plots, but soil reduction district showed a negative value, the reduced state was advancing, became apparently. Further from the fifth day, both test plots indicated stable numeric value, and soil solarization district always showed a positive value. In general, when Eh took a negative value, the activity of aerobic bacteria including bacteria wilt greatly reduced, and extinction in -100 mV below (Sinchon, 2000), the bactericidal effect became higher in soil reduction district, was expected.

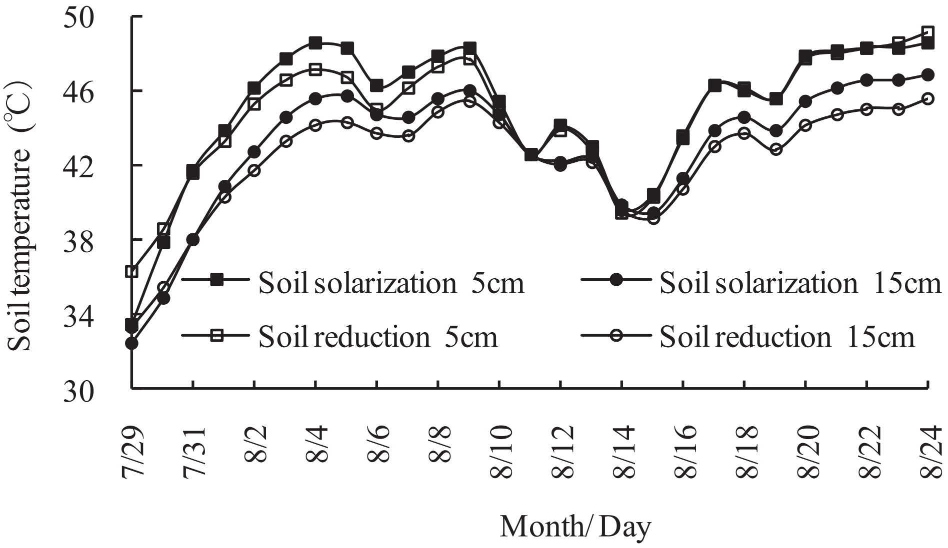


Fig 3.2 Soil temperature of soil solarization and anaerobic soil disinfection treatments of the glasshouse A1 in 2012

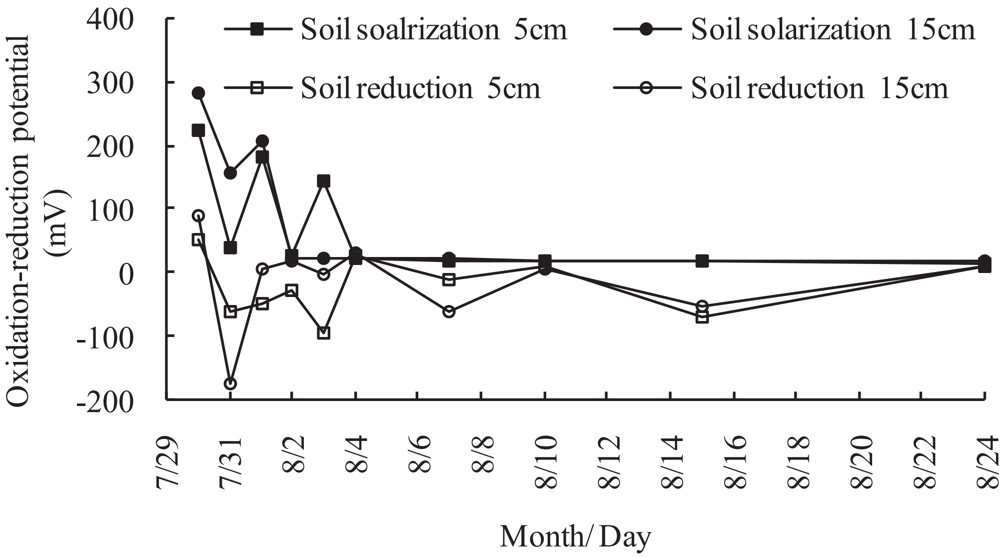


Fig 3.3 Oxidation-reduction potential of soil solarization and anaerobic soil disinfection treatments of glasshouse A1 in 2012

3.5 Effect of soil solarization

Table 3.3 showed population density of Ralstonia solanacearum before and after soil disinfection. The unit represented by the number of colony forming (cfu) of 1 g dry soil. The population density of R. solanacearum was different by different glasshouse even in the same year, also, it was different from year to year even in the same glasshouse, has been revealed.

The A1 glasshouse, before solarization *R. solanacearum* was not yet found in 2010, and was detected in the 15 cm depth in 2011 and 2012, after solarization it was not detected at all. The B glasshouse, before solarization it was detected in the 15 cm depth in 2010, in the 15 cm, 35 cm depth in 2011 and 2012, after solarization it was not detected in all layers except for point 1 in 2012. *R. solanacearu* was detected in the 15 cm depth of point 1 in 2012, it is believed that the reason that the days that soil temperature of this point consecutively exceeded standard temperature 40 ℃ were 9 days, were slightly lower than extinction days (10 days), then result in rising in soil temperature was insufficient slightly. However, as shown in Table 3.2, 3 years of A1 glasshouse, 2 years of B glasshouse in 2010 and 2011, the days that soil temperature of up to 15 cm depth consecutively exceeded standard temperature 40 ℃ during disinfection period were more than extinction days (10 days), then the above effect appeared, was considered.

The A2 glasshouse, the days that exceeded standard temperature 40 ℃ didn't exceed consecutive 10 days, but disinfection effect that after disinfection the population density of *R. solanacearum* decreased was confirmed. For it, soil temperature of up to 5 cm in 2011 and up to 15 cm in 2012 exceeded extinction days 3 days of soil reduction, the effect of the reduction treatment was found, which was considered. The C, D, and E glasshouse, both before and after solarization *R. solanacearum* was detected, all of them the disinfection effect was small, on the contrary, phenomena that the number of bacteria increased and the distribution area shifted to the deeper layer was observed. For these 3 glasshouses, didn't meet the condition of standard temperature 40 ℃ for consecutive 10 days.

Tomato of this district is planted in September after disinfection, it is a multi-stage cultivation with the harvest until July in the next year. For example, even in the A1 and A2 glasshouse in 2012, which had disinfection effect, after June of the harvest late stage, *R. solanacearum* has occurred with 10 % of A1 glasshouse, and 13 % of A2 glasshouse. For this, compared with the ground surface of high disinfection effect, bacteria remained in the deep layers which were from the main root group up to 30 cm depth, and it was considered that these bacteria expanded to near the surface. Therefore, soil solarization has been carried out each year in these glasshouses.

Table 3.3 Population density of *Ralstonia solanacearum* (cfu/g dry soil)

Glasshouse	Year	Height (cm)	Point 1		Point 2	
			Before	After	Before	After
A1	2010	15	0	0	0	0
		35	0	0	0	0
		50	0	0	0	0
	2011	15	4,078	0	0	0
		35	0	0	0	0
		50	0	0	0	0
	2012	15	3,769	0	3,446	0
		35	0	0	0	0
		50	0	0	0	0
A2	2011	15	16,178	0	0	0
		35	14,000	0	0	0
		50	10,442	1,024	8,366	1,024
	2012	15	21,270	1,101	9,168	2,919
		35	15,600	0	52,781	0
		50	18,524	2,967	22,624	0
B	2010	15	14,118	0	12,941	0
		35	0	0	0	0
		50	0	0	0	0
	2011	15	0	0	6,234	0
		35	0	0	4,078	0
		50	0	0	0	0
	2012	15	2,274	1,278	1,504	0
		35	1,617	0	0	0
		50	0	0	0	0
C	2012	15	2,593	0	1,587	2,083
		35	0	1,993	0	0
		50	0	1,571	0	0
D	2012	15	0	0	1,218	1,840
		35	0	0	0	0
		50	0	1,440	0	0
E	2012	15	7,722	7,384	5,600	2,157
		35	0	0	0	0
		50	0	0	0	0

Note: A2 glasshouse and point 2 of A1 glasshouse in 2012 were soil reduction

3.6 The amount of irrigation water

The purpose of irrigating the soil during disinfection, was to make the soil become the reduced state by an increase in soil moisture, increase the thermal conductivity of the soil and facilitate solar heat transmitted to the soil. In agricultural improvement popular plant in Gifu prefecture, it has been instructed that the field surface was did by the flooding state in the case of soil solarization, and irrigated with the degree no longer visible the entire soil surface. In actual survey, farmers referred to this criterion, and measured the amount of irrigation water by theirselves' judgment. The irrigation was performed with the irrigation tube that was laid under the multi, and combine the overflow of outer groove in some glasshouse.

Table 3.4 showed the survey results of irrigation situation. Irrigation once which was very different by different glasshouse, required 1-6 days, the irrigation time of almost of glasshouse was only once at the start of soil disinfection. There is almost no loss by evaporation from the soil surface because it was covered with a plastic multi in the soil solarization, from the measurement record of soil moisture content, soil moisture decreased slightly by penetration downward, during soil disinfection period, because it was able to confirm that the soil moisture of field capacity above was ensured, so the need for additional irrigation is less. As exceptional cases, B glasshouse in 2011 was irrigated twice for the purpose of water retention, soil temperature of 5 cm and 15 cm decreased by 5 ℃, 3 ℃, respectively, after 4 hours, soil temperature has recovered to the same extent as before irrigating. In addition, C glasshouse in 2012 was irrigated twice with the purpose of leaching the fertilizer component remaining in the soil, used a large amount of water (726.2 mm).

The amount of irrigation water required for soil solarization which was intend to realize rise in soil temperature and the reduction state of soil, it can be assumed that the amount of water requirement was the maximum with saturating the soil gap (100 % saturation), this value was equal to the sum of the gas phase volume ignoring penetration loss downward. According to Kodama et al (1984), *R. solanacearum* also inhabited to a depth of 1m from the soil surface. Therefore, the range of soil disinfection, from the surface to 1 m depth, was determined in this study, then the groundwater has been confirmed within 1 m (50~100 cm) in all of glasshouse. So from the surface layer to the groundwater level was made as target soil layer, and calculated the amount of water requirement to saturate from the gas phase ratio of each depth (the amount of gas phase, Table 3.4).

Because irrigation time was determined by the framing conditions such as planting schedule, soil moisture and groundwater levels conditions at the start of irrigation varied greatly by different glasshouse. Therefore, the calculated value of the amount of water requirement was 78.9~174.0 mm (Average: 119.8 mm) with saturating the soil gap, which varied greatly. In addition, irrigation was performed until the ground surface becoming the flooding state in fact, since it was difficult that stopped irrigation immediately after becoming the flooding state in farming work, and the penetration loss occurred. Thus, a number of irrigation was performed than the amount of water requirement to saturate the soil gap, the measured value of irrigation water varied widely by 155.6~726.2 mm. Among it, the C glasshouse was the maximum (726.2 mm), this is because it was also used as the leaching except soil solarization as described above. Furthermore, since soil temperature rise was insufficient, the C and D glasshouse didn't obtain the effect of soil solarization. So, when organized the amount of irrigation water of A1, A2 and B glasshouse with sufficient disinfection effect, the amount of irrigation water for soil solarization (A1, B) ranged from 155.6 to 495.2 mm (average: 291.3 mm), which corresponded to 104 %-346 % (average: 218 %) of the amount of water requirement from some state to become saturation state. On the other hand, the amount of irrigation water for soil reduction was the result of only A2 glasshouse, which ranged from 218 to 247 mm (average: 231.5 mm), which corresponded to 186~188 % (average: 187 %) of the amount of water requirement form some state to become saturation state.

Table 3.4 Comparison of the amount of irrigation water and water requirements for saturation

Glasshouse	Year	Area (m^2)	Irrigation day	The amount of irrigation (m^3)	The amount of irrigation (mm)	The amount of gas phase* ②	①／② (%)	Target soil layer (cm)
A1	2010	2,780	7/27～8/1	667.7	240.2	86.6	277	0-70
	2011		8/1	432.5	155.6	150.0	104	0-70
	2012		7/29	570.8	205.3	125.9	163	0-70
A2	2011	2,041	7/13	444.9	218.0	115.8	188	0-70
	2012		7/13-7/15	504.0	247.0	133.1	186	0-70
B	2010	2,041	8/5～6	962.8	471.7	136.2	346	0-70
	2011		7/28, 7/31	1,010.8	495.2	174.0	285	0-70
	2012		8/4～6	366.6	179.6	136.6	132	0-100
C	2012	3,223	8/23～26, 8/30～31	2,340.6	726.2	93.9	773	0-100
D	2012	1,257	7/24~25	202.0	160.7	78.9	204	0-50
E	2012	1,571	7/18~19	356.2	226.7	87.0	261	0-70
Overall	—	—	—	—	302.4	119.8	265	—
Average**	—	—	—	—	291.3	134.9	218	—

Note: 1) The amount of gas phase*: for each glasshouse, the average value in 2 points
2) Average**: Especially, the average value of A1 and B glasshouse with high disinfection effect

4 Conclusion

From the above results, it could confirm the adequate disinfection effect of tomato *R. solanacearum* in soil solarization, which was carried out in three out of the six surveyed glasshouse. After organization the actual conditions of irrigation water requirement in managing cultivation from the implementation status of soil solarization, the following findings were obtained.

(1) In this study, soil disinfection was carried out 6 glasshouses between 2010 and 2012 (total 11 times), soil disinfection period was 18~33 days (average: 24 days). It was also affected greatly by the weather conditions in the period, but if the disinfection period was short (for example 18 days), there may not be sufficient disinfection effect. Therefore, when weather conditions were unstable or didn't take a long disinfection period in farming, it was believed that the combination of the reduction process described below was effective.

(2) The maximum value of temperature difference between inside and outside of the glasshouse reached more than 10 ℃ (11.7~16.4 ℃), when airtight state of a glasshouse was not sufficient, the rise of temperature inside glasshouse was also not enough, the disinfection effect of soil reduced.

(3) According to previous studies of soil solarization, R. solanacearum was killed with daily average soil temperature greater than 40 ℃ for consecutive 10 days, with a combination of reduction treatment for consecutive 3 days, when it meets this condition, the bacterial count after disinfection significantly reduced, which was confirmed.

(4) Irrigation has been performed to the prospect until the field surface reaching the flooding state, from penetration loss to reach the flooding state or timing of the interruption of water supply, large amount of irrigation was performed than amount of

water requirement to saturate the soil gap. In this study, the amount of irrigation water for soil solarization with sufficient disinfection effect ranged from 155.6 to 495.2 mm (average: 291.3 mm), which corresponded to 104 %-346 % (average: 218 %) of the amount of water requirement from some state to become saturation state. On the other hand, the amount of irrigation water for soil reduction ranged from 218 to 247 mm (average: 231.5 mm), which corresponded to 186~188 % (average: 187 %) of the amount of water requirement form some state to become saturation state.

(5) The water of soil disinfection took a lot of water even among irrigation water requirement in managing cultivation, and in order to ensure the disinfection period, it is necessary to perform irrigation in short time, so concentration of water use seasonal was expected. So in farmland irrigation zone, the soil disinfection was performed, which was restricted by organizational capacity of transmission and distribution water facility, was feared.

III CONCLUSION

In recently years, more and more soil problem appeared in the world, for example soil erosion, soil pollution, soil alkalinity and salinity, soil-borne diseases and so on, which leads to soil degradation, and then caused a substantial reduction in the productivity of the land and agriculture production. Among them, countermeasure of soil salinization and soil-borne diseases problems were focused in my research.

Soil salinization has provided a serious threat for global agriculture throughout human history. It is becoming ever more prevalent as human land use intensifies in recent years, and the reclamation is one of major challenges in agroecology. Flood irrigation is a typical method for leaching saline soil. Yet the practice needs a large amount of water, and it is difficult to remove salt uniformly throughout soil layers. In this study, an experiment was conducted to evaluate leaching efficiencies of four irrigation methods, namely; flood irrigation, spray irrigation, paper-covered flood irrigation and puddling irrigation method. Flood irrigation was applied at three plots with different infiltration capacities. Spray irrigation, paper-covered flood irrigation, and puddling irrigation were applied at other three plots with medium infiltration capacities. Results showed that salt removal rates of flood irrigation tended to be higher near the surface of soil with smaller infiltration capacity, and that spray irrigation, paper-covered flood irrigation, and puddling irrigation were more efficient in removing salt than flood irrigation. Paper-covered irrigation was the only leaching method that reduced horizontal heterogeneities in salt content, while flood irrigation and puddling irrigation significantly increased the horizontal heterogeneities. The present study indicated that leaching efficiencies were highly affected by irrigation intensity and also by irrigation water volume only when irrigation intensity was considerably low, and that paper-covered irrigation is an efficient method in removing salt homogeneously from soil profile. Further studies need to be conducted to optimize irrigation intensity and water volume for given soil and water environmental conditions.

Soil-borne diseases are one of the major constraints to the production of various economically important crops, especially vegetables and ornamentals. In the last decades, soil fumigants such as methyl bromide were the most common approach to control soil-borne plant pathogens. Such chemical treatments, however, cause environmental hazards, and nonchemical soil disinfection methods are being widely pursued in recent years. Among them, soil solarization is one of the most promising methods to control soil-borne plant pathogens. In this study, the amount of irrigation water, soil temperature and population density of a pathogenic bacterium *Ralstonia solanacearum* before and after soil solarization were investigated in 6 greenhouses (located at Kaizu city, Gifu, Japan) in order to obtain the basic information of water requirement for the control of *R. solanacearum* via soil solarization in managing tomato cultivation. Our results showed that the soil temperature was influenced by airtight state of a glasshouse, temperature differences between inside and outside of a greenhouse, and duration and climatic conditions of the solarization period. The density of *R. solanacearum* decreased markedly after soil solarization with daily average soil temperature greater than 40 ℃ for consecutive 10 days or 3 days under anaerobic condition, which was consistent with previous studies. The amount of irrigation water ranged from 155.6 to 495.2 mm (average: 291.3 mm) for 2 greenhouses (A1, B) where soil solarization was effective, which corresponded to 104 %-346 % (average: 218 %) of the amount of water requirement from some state to become saturation state. On the other hand, the amount of irrigation water for soil reduction was the result of only A2 glasshouse, which ranged from 218 to 247 mm (average: 231.5 mm), which corresponded to 186~188 % (average: 187 %) of the amount of water requirement form some state to become saturation state.

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