Effects of soil mass watering and covering on *Tyrophagus similis* Volgin (Acari: Acaridae) soil densities

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(Received 15 December 2015; Accepted 12 May 2016)

ABSTRACT

*Tyrophagus similis* Volgin (Acari: Acaridae) is an important pest in the agricultural industry, causing extensive damage to new spinach leaves in greenhouses. Therefore, the development of effective control measures is necessary. The effect of mass-watered soil covered with a plastic film on *T. similis* densities was tested in the laboratory. Vinyl pots containing soil and released *T. similis* were mass watered. The soil surfaces of watered pots were closely covered with plastic film, except for the control. The densities of *T. similis* were significantly lower in the soil of pots that were covered for 10 or 14 d after watering than those in the control; however, no significant differences were found in the plot covered for 7 d. In 2015, the effect of mass-watered soil covered with a transparent vinyl film or a light-shading bilayer mulch film was investigated in three experiments in spinach greenhouses in Hokkaido. Although massive damage to the spinach was observed in plots covered with vinyl for 10 d, in most plots covered with vinyl and bilayer mulch for 14 d, *T. similis* densities were substantially lower and there was less damage than that observed in the control plots regardless of the soil temperature. However, in the plot where algae grew extensively on the soil during the covering period, *T. similis* densities increased rapidly and the spinach was severely damaged. Results indicated that mass watering and covering is effective to control mites; however, algal proliferation on the soil could cause mite densities to increase again, as algae is a suitable food source.

Key words: *Tyrophagus similis*, mass watering, vinyl covering, spinach greenhouse, algae, population densities

INTRODUCTION

The astigmatid mite species *Tyrophagus similis* Volgin (Acari: Acaridae) is an important pest that infests and deforms new spinach leaves growing in greenhouses (Kasuga, 2005; Nakao, 1989). The damage caused by the species has recently emerged as a nationwide problem (Kasuga and Amano, 2000). The mite usually inhabits soil at a 0–5 cm depth and mainly consumes organic matter (Kasuga and Amano, 2005; Kasuga and Honda, 2006b; Matsumura et al., 2009)
and algae on the surface of the soil (Honda et al., 2013) as a food source; however, it is possible that when the soil environment becomes unsuitable for survival, some mites migrate aboveground (Honda et al., 2015; Saito et al., 2014) settling in the new leaves of spinach, resulting in crop damage.

Although insecticides applied superficially through spraying are normally used to control this species, they generally do not permeate the soil effectively, and therefore do not frequently reach all the mite habitats. Moreover, one of the most effective insecticides, DDVP (dimethyl-2, 2-dichlorovinylphosphate; 2,2-dichloroethenyl dimethyl phosphate) (Itoyama, 2008; Kasuga and Amano, 2002; Matsumura and Kamikawa, 2009; Nakao et al., 2000), was discontinued in 2008. As a result, alternative methods of pest control are necessary. Soil disinfection methods using chemicals, solar heat, steam, or hot water have effectively reduced mites in the soil (Asano, 2012; Ito et al., 2005; Matsumura et al., 2005; Yasukawa et al., 2011); however, these methods usually require long processing times resulting in reduced harvest frequency. Therefore, new control methods that are effective within a short period are needed for the agricultural industry.

Matsumura et al. (2012) showed that the mite population density decreased in soil that was exposed to rainfall during the off-season, possibly from continuous excessive soil moisture or compressed soil. These conditions are possibly unsuitable for mite survival or reproductive behavior, although mites prefer moderate humidity (Kasuga and Amano, 2000). Therefore, it is possible that the mass watering was considered to be effective to control mites even during the farming season, after harvesting before the next seeding. However, Saito (2015) suggested that mass watering alone did not control the mite population; instead, the mite population density increased. Mites have a high water tolerance, approximately 70% of the mites survived for 12 d at the surface of the water, and 80% survived for 5 d of being submerged (Matsumura et al., 2012). In the previous experiment, the soil water dried rapidly by transpiration from the surface of the soil so that tilling could take place within 7 days; however, the moderate moisture content remaining in the soil may have resulted in an increase in *T. similis* densities.

Therefore, it seems necessary that high moisture conditions should be maintained longer to decrease *T. similis* densities. In the present study, mass-watered soil was covered with film to retain the moisture and investigated in the laboratory and in greenhouses. Although, *T. similis* is negatively affected by high temperatures (Kasuga and Honda, 2006a), the effect of temperature during the covering period should be analyzed; transparent vinyl film or light-shading film was used to cover materials to increase or decrease the soil temperature, respectively. In addition, wet soil that is exposed to sunlight is generally a suitable habitat for algal growth, which in turn is a suitable food source for *T. similis* (Honda et al. 2013); the effect of algae on the soil immediately after cover removal on the mite density was also observed.

**MATERIAL AND METHODS**

1. **The effect of mass watering and covering of soil on *T. similis* densities in the laboratory**

The culture line of *T. similis* obtained in 2010 was established by the Nara Prefectural Agricultural Experiment Station and was originally obtained from a spinach greenhouse at Uda, Nara in April 2003. It has since been maintained in the laboratory using dry yeast (EBIOS, Asahi
Food and Health Care) as food on filter paper in a plastic container at 20°C, 80% RH, and 24-h dark. *T. similis* (500 individuals of per pot) were released into 36 vinyl pots (15 cm diameter, 20 cm height, 2 cm diameter of hole on the bottom covered with 2-mm plastic mesh) containing 1,100 g of sandy loam soil with 15% (w/w) water content that was collected from the spinach greenhouse of the Hokkaido Research Organization, Central Agricultural Experiment Station (Naganuma, Hokkaido, Japan). To ensure the soil held the maximum amount of water, the pots were watered excessively (approximately 1,000 mL per pot) with a sprinkling can, and the surplus water drained through the hole on the bottom. After the surplus water in each pot was completely drained, the soil surfaces of 18 pots were closely covered with plastic film (Tunnel ace, thickness 0.05 mm, Mitsubishi Plastics Agri Dream Co., Ltd.) as the processed plots to retain the water. The other 18 pots were left uncovered as control plots. All pots including the control were maintained at 21°C and 24-h dark in the plastic containers (450 × 350 × 300 mm). The films in each processed plot were removed after 7-, 10-, and 14-d, respectively (six pots per plot; i.e., each plot had six repetitions). The uncovered pots were maintained for 3 d in the container to dry the soil. The *T. similis* densities in 100 mL of soil (0–5 cm depth) from each processed plot were compared with those of the control plot using a Tullgren apparatus.

### 2. The effect of mass watering and covering of soil on *T. similis* densities and crop damage in greenhouses

In 2015, three experiments were performed at three greenhouses in the Central Agricultural Experiment Station.

In Experiment (Ex.) 1 (April to June), the soil was tilled with a sulky-type rotary (CX1508S, Matsuyama Co. Ltd.) and divided into 21.3 m² (8.5 × 2.5 m) each as a repetition with levee sheets (25 cm height) buried at about 15 cm. Each processed plot had two or four repetitions, and the control plot had four repetitions. In Exs. 2 (June to August) and 3 (August to October), the divisions prepared in Ex. 1 were rearranged and tilled using a small-sized rotary (F220, Honda Motor Co., Ltd.) immediately before mass watering. Each plot in these experiments had two repetitions.

In each experiment, approximately 500 *T. similis* individuals/m² were released 1–4 days before mass watering. Processed plots were covered with two types of films to analyze the effects of temperature and occurrence of algae: a transparent agricultural vinyl film (Nobi Ace Mirai, thickness 0.15 mm, Mitsubishi Plastics Agri Dream Co., Ltd.) to raise the temperature, or a light-shading bilayer mulch film (white and black double mulch, thickness 0.02 mm, Mikado Chemical M. F. G. Co., Ltd.) to lower the temperature. Thereafter, 200 mm of water was applied via five watering tubes (Ever flow type A, Mitsubishi Plastics Agri Dream Co., Ltd.) arranged under the film. In Ex. 1, light-shading mulch was not used and the soil was covered with vinyl for 10 d or 14 d, and the entire process was repeated twice or four times, respectively. In Exs. 2 and 3, the soil was covered for 14 d with each material. In the control plot, mass watering was not performed, but 30 mm of water was applied 2–4 d before seeding to ensure the moisture of the soil surface at the seeding period was the same as that of the processed plots. Three to seven days after the covers were removed, chemical fertilizer (S555, 15.0% nitrogen, Katakura & Co-op Agri Co., Ltd.) and fermented chicken manure (Fujimi fermented chicken manure pellet, 2.5% nitrogen, Fujimi Industry Co., Ltd.) were applied at an amount of 8 kg/10 ares and 4 kg/10 ares.
nitrogen, respectively. After the soil was tilled using a small-sized rotary, spinach (Exs. 1 and 3, cultivar ‘Triton’, Sakata seed Co., Ltd.; Ex. 2, cultivar ‘Brighton’, Sakata seed Co., Ltd.) was seeded at intervals of 7 cm between plants within rows, with a ridge spacing of 20 cm between rows using a seeding machine (HS-801, Mukai Industry Co., Ltd.).

The temperature at the surface and 5-cm depth of the soil in each plot was measured hourly when covered using a temperature data logger (TR-71U, T&D Co., Ltd.). Immediately after the cover removal, 20 mL of soil (0–1 cm depth) was collected from three random areas of each repetition, and the soil moisture contents were determined as follows; \( \frac{\text{weight of fresh soil} - \text{weight of dried soil (24 h, 105^\circ C)}}{\text{weight of fresh soil}} \times 100 \). Moreover, the occurrence of algae on 900 cm\(^2\) (30 × 30 cm) of the soil surface was recorded in three random areas of each repetition just before fertilization using the following index referring to the method for measuring weed coverage in lawns (Furuya, et al., 1979): 0, no algae present; 1, minimal algae present (< 5% occupancy); 2, algae present in various places (5 to 25% occupancy); 3, large algal colony present (25 to 50% occupancy); 4, algae covered the majority of the soil surface (> 50% occupancy). The extent of algal occurrence was calculated as follows: \( \frac{\text{the sum total of indexes}}{\text{the number of observed spots}} \times 4 \times 100 \). The \( T. \ similis \) density in 100 mL of soil (0–5 cm depth) was investigated in three random areas of each repetition at 4- to 7-d intervals after seeding (soil was collected 5–8 times from seeding to harvesting in each experiment). Three acarid bait traps (Konadani Mihariban, Sankei Chemical Co., Ltd.) that reflected the density of mites moving on the soil (Honda, 2012) were placed between plants in each repetition in the evening and the \( T. \ similis \) density collected was determined the following morning at from 1- to 4-d intervals. The damage to spinach was observed in 25 plants in each repetition at approximately 7-d intervals using the following index: 0, no damage; 1, slightly damaged; 2, slightly deformed; 3, deformed; 4, greatly deformed, dwarfing. The extent of the damage was calculated as follows: \( \frac{\text{the sum total of indexes}}{\text{the number of observed spinach}} \times 4 \times 100 \).

RESULTS

1. **The effect of mass watering and covering of soil on \( T. \ similis \) densities in the laboratory**

   In the plot covered for 7 d, there were no significant differences in \( T. \ similis \) densities compared with those of the control (t-test, \( p < 0.05 \)) (Fig. 1). In the plots covered for 10 and 14 d, the \( T. \ similis \) densities were significantly lower than those of the control plots (t-test, \( p < 0.05 \)).

2. **The effect of mass watering and covering of soil on \( T. \ similis \) densities and crop damage in greenhouses**

   Although the density of \( T. \ similis \) in the soil of the plot covered with vinyl for 10 d was lower than that in the control plot until four weeks after seeding, the extent of damage at harvesting was higher than that of the control plot (Fig. 2).

   In the all plots covered with vinyl or light-shading bilayer mulch for 14 d, except for the plot covered with vinyl in Ex. 2, \( T. \ similis \) soil and trap densities during cultivation remained lower than those of the control plots (Fig. 2–4). Despite the \( T. \ similis \) densities in traps and spinach damage that was observed 3–4 weeks after seeding, the damage at harvesting was less than half of that in the control plots (Fig. 2, Fig. 4). However, in the plot covered for 14 d with vinyl in Ex.
**Fig. 1.** *Tyrophagus similis* density from 100 mL of the 5-cm depth surface soil after mass watering and covering in the laboratory. The error bars represent standard error. The asterisks show the significant differences compared with the control plot (t-test, $p < 0.05$).

**Fig. 2.** (A) *Tyrophagus similis* density at 5-cm depth from the soil surface per 300 mL of soil suspension, (B) the number of *T. similis* captured using acarid bait traps, and (C) the extent of damage to spinach leaves in Experiment 1. The mass-watered soil was covered with vinyl for 10 or 14 days.
2, the *Tyrophagus similis* density increased rapidly from 1 week after seeding, and trap density was much higher than that of the control, with spinach damage at harvesting higher (extent of damage; 76) than that in the control plot (extent of damage; 50) (Fig. 3).

The accumulated time to reach more than 40 or 45°C on the surface and in the soil (5-cm depth) in each experiment was longest in the plot covered with vinyl; and in the plot covered with light-shading bilayer mulch, it was similar to that of the control plot (Fig. 5). The soil moisture content of the plot immediately after cover removal was higher than that of the control plots (Fig. 6). The plot covered with vinyl in Ex. 2 with an increased *T. similis* density showed large-scale algal growth in both repetitions (Fig. 6).

**DISCUSSION**

In the previous report where the mass-watered uncovered soil did not effectively reduce *T. similis* density (Saito, 2015), it is possible that the soil water content decreased rapidly through transpiration and the soil habitat became more suitable for mites. However, in the present study, mass watering and covering of the soil for 14 d effectively controlled the *T. similis* density. Since
the controlling effect was not observed in the plot after 7 d in the laboratory and 10 d in the greenhouse, the increased duration of the high moisture content should essentially reduce the density of *T. similis*.

*T. similis* survives more efficiently at lower temperatures, and adult mortality occurs when exposed to temperatures of 40°C for 24 h and 45°C for 3 h (Kasuga and Honda, 2006a). Matsumura et al. (2005) reported that the mites could be controlled using solar heat sterilization, with a process similar to mass watering and covered soil, but at high temperatures. Therefore, the applicability of this method is considered to be limited to summer when the temperature is high. However, in the present study, although the temperature in the 5-cm soil depth did not reach 40°C in the plot covered with light-shading bilayer mulch, the mite population was almost the same as that on the plot covered with vinyl. This result suggests that continuous excessive soil moisture is more important than high temperatures to induce mite mortality.

Saito (2013) reported that the density of *T. similis* increased dramatically in the soil mixed with organic materials. Although Honda et al. (2013) suggested the algae on the surface of the soil is a suitable food source for the mite, the soil mixed with algae could possibly be suitable for increasing the mite density. In the plot of Ex. 2 where massive damage occurred despite 14 d of

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**Fig. 4.** (A) *Tyrophagus similis* density at 5-cm depth from the soil surface per 300 mL of soil suspension, (B) the number of *T. similis* captured using acarid bait traps, and (C) the extent of damage to spinach leaves in Experiment 3. The mass-watered soil was covered with vinyl or bilayer mulch for 14 days.
Fig. 5. Total time taken for the temperature of soil at the surface (A) and at 5-cm depth (B) to reach higher than 40°C or 45°C. Vinyl represents the plots covered with vinyl and mulch represents the plots covered with bilayer mulch.

Fig. 6. (A) Soil moisture content at 1 cm from the surface, and (B) the extent of algae on the soil surface immediately after removing the covers. N.D. indicates not dated. Vinyl represents the plots covered with vinyl and mulch represents the plots covered with bilayer mulch.
covered soil, the high algal content of the soil surface could result in a rapid increase of mite density when it was mixed with soil by tilling.

Therefore, to obtain a stable reduction in mite density, algal control may also be required. Furthermore, because algae require light for growth, light-shading materials such as the bilayer mulch film used in present study are more adequate than transparent covering. This could be confirmed in further research in the future.

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摘要
土壌への多量灌水および被覆のコナダニ密度低減効果
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2015 年 3 月に温度条件 21℃, 全暗条件の室内でホウレンソウケナガコナダニ *Tyrophagus similis* Volgin（以下コナダニと略）約 500 頭を放飼した土壌を充填した直径 15 cm のビニルボットに, 約 1 L/ ポット相当の多量灌水をし, 土壌表面にビニルを密着させ静置したところ, 7 日間被覆ではコナダニ抑制効果が得られなかったが, 10 および 14 日間被覆では多量灌水のみと比較してコナダニ頭数が顕著に少なくなった. また, 2015 年 4 ～ 10 月に北海道立総合研究機構中央農業試験場のコナダニを放飼したホウレンソウ圃場において 200 mm の灌水を行い, ビニルまたは白黒マルチで被覆する試験を 3 回実施した. ビニル 10 日間被覆では被害が多発したが, 14 日間被覆ではほとんどの場合で慣行区と比較して土壌中コナダニ密度が低く推移し被害程度も低い傾向が見られた. 被覆下の温度の違いによる効果の差は見られなかったが, 被覆期間中に土壌表面に藻類が発生した区においてコナダニ密度が急速に回復し被害が多発する事例が見られた.