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High-Pressure Water Technology to Control San Jose Scale (*Quadraspidiotus perniciosus*) (Hemiptera: Diaspididae) on Apple Crops

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ABSTRACT
Quadraspidiotus perniciosus (Comstock) known as San Jose scale is one of the most destructive apple pests in the world. San Jose scale damage all parts of the apple crop throughout the year. The research was conducted to determine the effectiveness and efficiency of High-Pressure Water (HPW) to manage San Jose scale and the impact on non-target arthropods of apple crop. The observation of San Jose scale population at 24 plants was conducted every day. The observation of non-target arthropods was done visually with a radius of 1.5 meters, then identified up to family level. In addition, it was observed the effect of HPW to the apple crop by observing morphological and physiological changes of the stems on apple crop. The result showed the combination of HPW to the population of San Jose scale significantly different from controls (Pesticide application). Initial population of San Jose scale before application were 100-200 individuals, after application became 0-10 individuals, whereas the control population remained higher. Non target arthropods diversities increased after the application of HPW. Non target arthropods were consisted of 17% pests, 38% detrivor, 23% pollinators, 4% parasitoids, and 18% predators. High Pressure Water did not have negative effect on apple crop.

Keywords: Quadraspidiotus perniciosus, *high pressure water*, *non-target arthropods*, *apple pest*

1. INTRODUCTION

Pest is one of important aspects that can reduce agriculture productivity significantly and very important to be managed. One of them is the problem of San Jose scale (*Quadraspidiotus perniciosus* Comstock) as a major pest in apple crop. San Jose scale attacks the root, stems, leaves and fruit of the apple crop throughout the year. Resulting in severe damage to the apple crop and eventually will die [1]. Figure 1 showed the symptom of this pest on stem and fruit of apple.

Figure 1 Symtomps of *Quadraspidiotus perniciosus* on apple crop: (a) stem, (b) fruit

Currently, the control of San Jose scale is still dependent on pesticides. Farmers in Batu city, Malang, East Java use pesticides without regard to the recommended dose. The application of pesticides is in very high intensity caused resistance and resurgence of San Jose scale. There have been population explosion of San Jose scale in the last five years. In 2010, there was population explosion of San Jose scale with an area of 300 hectares. Data of apple harvest land area in the Batu City has decreased by 25.73% from 2010-2014 [2]. High Pressure Water (HPW) is one of the innovations to control San Jose scale by mechanical removal methods with high pressure (1000 psi).

High Pressure Water can substitute pesticides. In addition, HPW is expected to restore the balance of the apple plantation ecosystem that is previously impaired due to the intensive use of pesticides. The agricultural sector is progressing very rapidly. Therefore, the current crop of Integrated Pest Management becomes the main concentration, because the impact is not damaging the environment and the use of pesticides with low intensity. Thus, Ecological Engineering to manage San Jose scale is necessary [3]. This research aimed to observe the effectivity of HPW and its combination with lime sulphur againts San Jose scale.

1.1. Materials and Methods

This research was conducted in the experimental field and Entomology Laboratory of Indonesian Citrus and Subtropical Fruit Research Institute, Batu City. This research was done from October 2015 to March 2016.

1.1.1. Experimental Design

The experiments used a Randomized Complete Block Design (RCBD), a 10 years old apple crop was used in this research. It used four treatments and six replications. The first treatment was High Pressure Water (HPW), the second treatment was HPW and Lime sulphur, the third treatment was Lime sulphur, the control or fourth treatment was pesticides application by farmers.

The first treatment was HPW spray (pressure: 1000 psi), applied to all parts of the apple tree to manage San Jose scale. This treatment was a mechanical management by removing San Jose scale physically from the apple tree. HPW was applied using flat nozzle with radius 10 cm.

The second treatment was HPW and lime sulphur which HPW spray (pressure: 1000 psi) was applied to all parts of the apple tree to manage San Jose scale. After the HPW treatment was done, additional treatment was applied with lime sulphur application on stems that were useful to prevent San Jose scale return and made San Jose scale could not adapt to the micro environment. It led to the habitat of the pest management. Figure 2 showed the making of lime sulphur. Lime sulphur was then brushed on the apple stem of 1.5 m using a 4-inch brush.

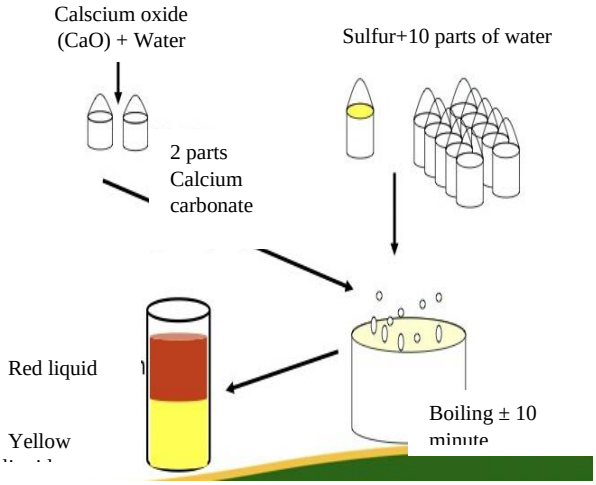


Figure 2 The making of lime sulphur

The third treatment was applied with lime sulphur only on stems. This treatment was a mechanical management by removing San Jose scale physically from the apple tree. Lime sulphur was applied using 4-inch brush with brushed on the apple stem of 1.5 m.

The fourth treatment was pesticides used to control San Jose scale by farmers. Pesticide that was used containing active compounds of cypermethrin and dimethoate. These pesticides were sprayed to the stem every week.

1.1.2. Field Observation

1.1.2.1. San Jose scale population (Q. perniciosus)

San Jose scale infestation observed on all stadia. Population Observations by counting all San Jose scale phases on tertiary stem (24 plant samples). Observations were conducted every day. Observations using the parameter number of the San Jose scale at all stadia on the tertiary stem, the individual units were San Jose scale. San Jose scale infestation rate was calculated by using the infestation rate assessment (Table 1). The level rate of infestation by [4, 5].

1.1.2.2. Non-target arthropods diversity on apple crop

Observations were conducted every day by using two methods: direct view (visual) and relative observations using sweep net and aspirator on apple plantation within radius of 1.5 meters from a tree. Aspirator was used to take direct samples of non-target arthropods that could be found on the specified radius. Then, the samples were immediately preserved to be classified based on its taxonomy through identification up to family level using Borror identification book [6]. To understand the arthropod diversity on every treatment, Shannon-Wiener and Simpson Index were used as follows [7].

1.1.2.3. Morphological and physiological effects on apple crop

Observations were conducted every day by observing changes in physiological and morphological effects on apple crop, as well as morphological and physiological changes of stems in the tertiary section.

1.2. Our Contribution

High Pressure Water as a technology to manage San Jose scale that are effective, efficient and environmentally friendly. The benefit is to make apple commodity free of chemical pesticides, healthy for consumer and can be exported, soas to provide additional value to the apple farmers.

1.3. Paper Structure

The paper is organized as follows. Section 2 introduces the preliminaries used in this paper, control model. Section 3 presents the effect control with HPW. Finally, the paper presents direction for future research.

Table 1 The level of infestation for San Jose scale

Categories	Infestation	Description
0	No infestation	No colonies found in the plant
1	Isolated infestation	Only scattered single individuals
2	Medium infestation	Small colonies of 2–10 are found
3	Severe infestation	Large colonies of 11–100 are found
4	General or layered infestation	Scales completely cover the infested parts of the plant

2. RESULTS AND DISCUSSION

It was a successful application of HPW on apple Crops to control San Jose scale. HPW suppressed the San Jose scale significantly, it indicated that San Joses scale could be removed from apple tree with simple treatment without pesticide. HPW made San Jose scale died with pressure 1000 psi. Non target arthropods increased after application of HPW on apple plantation and did not have negative effect for apple plantation. HPW without combination lime sulphur is very cheap to applied by farmer. The result was not significant between the treatment, it means that farmer could use the minimum cost to manage San Jose scale with HPW without combination. HPW and lime sulphur resulted good outcomes, it could suppress the San Jose scale population with long period. Lime sulphur block made Habitat management for San Jose scale on Apple Plantation. This treatment increased non target arthropods on apple plantation especially natural enemies of San Jose scale increased during this treatment.

2.1. San Jose scale Population on HPW and Combination of Lime Sulphur

Population was the main factor for monitoring San Jose scale on apple crop. The population dynamic should be decreased by application of HPW (Figure 2). Population consisted all stadia of San Jose scale who attacked apple crop. The most stadia found was crawler it was successfully applied with High Pressure Water in January 2016. HPW resulted good outcomes, before application, the population of San Jose scale was 100-200 individual per 5x10 cm observation areas. The HPW decreased population of San Jose scale very significantly until zero individual. Category of infestation before applied HPW was heavy infestation (Scales completely cover the infested parts of the plant). HPW applied on apple crop made the population of San Jose scale decreased. Day 2-21 after application made the population to be categorized to no infestation and isolated infestation (Only scattered single individuals found). Day 22-33 the population increased and categorized to medium infestation (Small colonies of 2-10 are found). It could happen because HPW was not optimally applied on apple plantation. HPW should be applied intensively to knock down all colonies of San Jose scale with high pressure (1000 psi).

The analysis variance between HPW and control were significantly different, but the DMRT test between HPW and combination were not significantly different, this research used 0.05 significant level. The HPW and combination of lime sulphur resulted the same outcomes, that San Jose scale population decreased from heavy infestation to no infestation/isolated infestation. It could happen because the main application of the three treatments were High Pressure Water. Hence, the DMRT results were not significantly different.

This research observed application durability for HPW and combination. HPW without combination could suppress San Jose scale population for 1 month. Then, the San Jose scale population increased to isolated infestation. HPW and Lime sulphur could manage San Jose scale for 3 months, because lime sulphur optimally managed the habitat of San Jose scale. This combination should be re-applied to manage San Jose scale. HPW can manage San Jose scale sustainability, because the natural enemies could balance the ecosystem on apple plantation. Natural enemies were the best method for Managing San Jose scale and create sustainability.

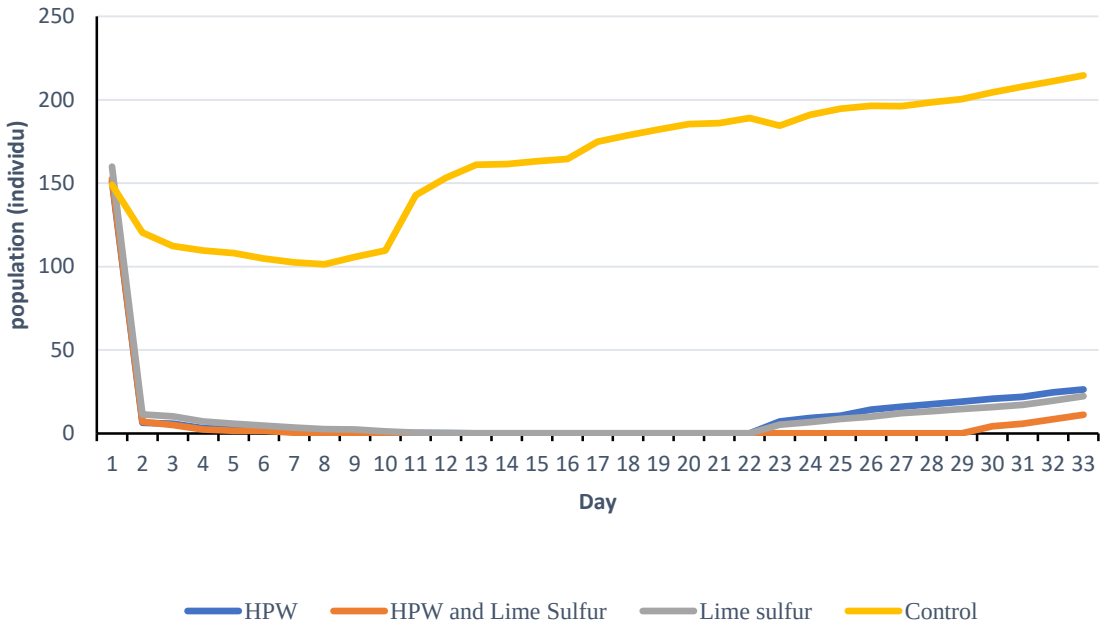


Figure 3 Population dynamic of San Jose scale

2.2. Non-Target Arthropods Diversities on Apple Crop

The application of HPW and combination resulted the diversity and population of non-target arthropods increased. The Shannon-weaver index used to understand the level of diversity. The three-treatment results were high diversity, because the Shannon-weaver index more than three. The control had medium diversity. The Simpson index used to understand the complexity of non-target arthropods in apple plantation. The highest complexity was found in the combination of Lime Sulphur block, the second was the combination of HPW and Lime sulphur and without combination with same value, and the lowest complexity was in control (Table 2).

2.3. Morphological and Physiological Effect on Apple Crop

The application of HPW and combination had morphological and physiological effect on apple crop. The different effect caused by HPW and combination was due to the application on apple crop. The application of HPW and combination targetter on the apple stem that found to be heavy infested by San Jose scale (Table 3).

The San Jose scale, *Q. perniciosus*, is still considered as one of the most destructive apple pests in the world. It becomes very difficult and at times almost uneconomical to control because high intensity of pesticide application, non-target pest on the list of pesticide and resurgence of the pest. San Jose scale attacked apple in the Batu city with heavy infestation. San Jose scale becomes an important pest species since 2010 until now. San Jose scale becomes resistant and resurgent due to the high use of pesticides such as the case in Batu city.

It started in 2010, continued to 2012 when the observation conducted on apple plantation. All apple tree at that time required as many as three-time sprays in one week. The crop was not always commercially clean of San Jose scale infestation. In 2010, the quantity and quality of apple crop were decreased. The fruit was unexportable because it was too heavily infested with San Jose scale (Figure 3). There are usually four generations a year. The life cycle of San Jose scale in tropical country is three cycles in one year. One of the cycles is destructive phase on apple crop. If heavy scale infestations are left unchecked, trees may be seriously damaged, resulting in reduced vigour, thin foliage, cracked or dying branches, and the eventual death of the tree. Young trees may be dead before fruiting. Infested fruit develop a reddish-purple ring surrounding each spot where a scale settle.

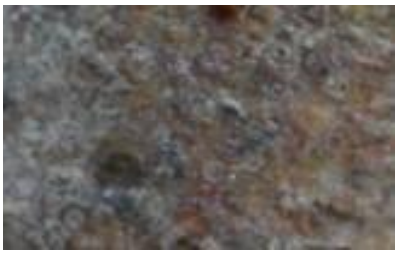
Excessive population of San Jose scale can pose a serious threat to the health of the apple tree by causing defoliation as well as dieback of branches. Farmer has done everything to control San Jose scale, but the result is still unsuccessful. San Jose scale has developed resistance to chemicals. Meanwhile, consumers desire less chemicals on their produce, it would be desirable to develop a nonchemical method to managed San Jose scale. HPW is

successfully applied in the packhouse at consolidated citrus estates, Letaba. A large percentage of the citrus crop from 450.000 trees was not exportable because the fruit was heavily infested with red scale, even after passing over the brushes in the packhouse with HPW, so that red scale and other scale insect were physically removed [8]. The average population for California red scale was about 15%, but the spray unit with HPW reduced culls to between 0–0.2%. The application of HPW on apple crop has never been done. This research was the first application of HPW on apple crop to manage San Jose scale. It applied on stem of apple crop with High Pressure Water (1000 psi). The trial, with pressure (1000 psi) could physically remove San Jose scale from apple tree. This mechanical control required only water without pesticide.

Table 2 Non target arthropods diversity analysis

	Treatment			
	HPW	**HPW and Lime sulphur**	**Lime sulphur**	**Control**
Order	7 Diptera:3 Hymenoptera: 3 Homoptera : 1	7 Diptera:3 Hymenoptera: 3 Homoptera : 1	7 Diptera:3 Hymenoptera: 3 Homoptera : 1	5 Diptera:3 Hymenoptera: 2
Family	13 **Diptera: 7** Muschidae, Drosophilidae, Tipulidae, Tephritidae Dolichopodidae Culicidae Simuliidae **Hymenoptera: 4** Vespidae Ichneumonidae Formicidae Apidae **Homoptera: 1** Cicadellidae **Coleoptera: 1** Coccinelidae	13 **Diptera:7** Muschidae, Drosophilidae, Tipulidae, Tephritidae Dolichopodidae Culicidae Simuliidae **Hymenoptera: 4** Vespidae Ichneumonidae Formicidae Apidae **Homoptera: 1** Cicadellidae **Coleoptera: 1** Coccinelidae	14 **Diptera:7** Muschidae, Drosophilidae, Tipulidae, Tephritidae Dolichopodidae Culicidae Simuliidae Tabanidae **Hymenoptera: 4** Vespidae Ichneumonidae Formicidae Apidae **Homoptera: 1** Cicadellidae **Coleoptera: 1** Coccinelidae	9 **Diptera:5** Muschidae Drosophilidae, Tephritidae Simuliidae Tabanidae **Hymenoptera: 4** Vespidae Ichneumonidae Formicidae Apidae
Individual	4520	4301	5751	4021
Shannon-Wiener index (H)	3.25	3.21	3.48	2.94
Simpson index (D)	0.96	0.96	0.97	0.87

Table 3 The morphological and physiological changes on apple crop

Treatment	Before treatment	After treatment
HPW		
HPW and Lime Sulphur		
Lime Sulphur Block		
Control		

Therefore, HPW can be a technology to manage San Jose scale that were environmentally friendly, free pesticide application, effective and efficient High-Pressure Water should be followed with good timing and weakest phase of San Jose scale. The weakest phase of San Jose scale was before the adult female emerged the first crawler, because one adult female produced 400 crawls. If HPW applied, it made the crawler died before emergence. This research applied HPW in early January. It was good timing to applied because in January the crawlers of the third generation were released, and during this time there was considerable overlap between stages during the third generation. The destructive generation of San Jose scale occured in the third generation. They were very destructive for host crop. The application of High-Pressure Water before the 3rd generation prevented San Jose scale to destroy the apple trees.

2.4. San Jose Scale Population on Lime Sulphur

High Pressure Water could remove San Jose scale from apple trees. The mechanism of HPW San Jose Scale was by washing the trees especially the stem part of apple crop. The High-Pressure Water with 1000 psi destroyed the body of San Jose scale in all phase. It was very effective and efficient to manage San Jose scale because it consisted of water without pesticide. High Pressure Water was easy to use and apply by farmer. Farmer could decrease the maintenance cost for managing San Jose scale. The lime sulphur has main function to prevent San Jose scale return to the trees if the phase is crawler or male. It was done with lime sulphur which made San Jose scale could not adapt to the micro environment. It suppressed the disperse of San Jose scale [9].

On the other hand, lime sulphur has many functions to manage pest in apple crop. It can supress growth and development of pathogenic fungi, moss, and the other surface pest. Lime sulphur makes pathogenic fungi died because the micro environment does not support the pathogen life. Lime sulphur is one of the best methods to apply in stem and it can be used also as fertilizer for apple crop. The main component of lime sulphur is Sulphur (S) and Calcium (Ca). The two components are macro nutrient for apple crop. It is very important for apple growth and development, especially Ca make the cell wall more thicker and difficult to attack by the pest [9].

The environment factor consists of temperature and relative humidity generally affected the population of San Jose scale. It has specific condition for living. The optimum temperature is 25-29°C. The highest relative humidity makes the crawler emerge, and the growth and development of San Jose scale are optimal on apple crop. The temperatures below 25°C and up to 30°C resulted highest mortality. The decreasing point of relative humidity made the San Jose scale could not emerge the crawler [10].

3. CONCLUSION

High-Pressure Water is one of the best control method for San Jose scale, because the component is just water without pesticide. It is effective and efficient to control San Jose scale and did not affect the non-target arthropods. The stem has increased its elasticity due to the application of HPW and the combination of lime sulphur.

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