MANAGEMENT OF WHITE MANGO SCALE, *Aulacaspis tubercularis* (HOMOPTERA: DIASPIDIDAE) USING PRUNING, OILS AND PESTICIDES IN EASTERN WELLEGA, ETHIOPIA

M.Sc. THESIS

By

Yohannes Atnafu

March, 2020

Jimma, Ethiopia

MANAGEMENT OF WHITE MANGO SCALE, *Aulacaspis tubercularis* (HOMOPTERA: DIASPIDIDAE) USING PRUNING, OILS AND PESTICIDES IN EASTERN WELLEGA, ETHIOPIA

M.Sc. THESIS

By

Yohannes Atnafu

A Thesis
Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture

Advisor - Wakuma Bayissa (PhD)

Co-Advisor- Belay Habtegebriel (PhD)

March, 2020

Jimma, Ethiopia

Jimma University College of Agriculture and Veterinary Medicine

Department of Horticulture and Plant sciences

Approval Sheet for Thesis Research

Name of student: Yohannes Atnafu Belay   ID N0. RM 1208/10

Program of study: Master of Science in Horticulture

Title: MANAGEMENT OF WHITE MANGO SCALE, *Aulacaspis tubercularis* **(HOMOPTERA: DIASPIDIDAE) USING PRUNING, OILS AND PESTICIDES IN EASTERN WELLEGA, ETHIOPIA**

I have completed my research work the approved proposal and it has been evaluated and accepted by my advisors. Hence, I hereby kindly request the department to allow presenting the findings of my work and submitting the thesis.

Name of student: **Yohannes Atnafu** Signature_______________Date __/03/2020 G.C

We have agreed to supervise the thesis research work. We have evaluated the content of the proposal, found to be satisfactory, complete, and according to the standards and formats of the university. We have also verified that the work has not been done anywhere else before.

Major Advisor: **Wakuma Bayissa (PhD)** ______________ ____________

Name Signature Date

Co-advisor: **Belay Habtegebriel (PhD)** ________________ ____________

Name Signature Date

Decision/suggestion of department graduate council (DGC)

____

________________________ ____________________ ____________

Chairperson, DGC Signature Date

________________________ ____________________ ____________

Chairperson, CGS Signature Date

DEDICATION

This work is dedicated to my grandmother Emmuhay Nigstie Gebrewahid. A special feeling of gratitude my loving grand mom her word encouragement and push for tenacity ring in my ears. She also always prays to me and her committed support in the success of all my life.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my work. I have followed all ethical and technical principles of scholarships in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in this thesis has been given recognition through citation.

This thesis is submitted in partial fulfillment of the requirements for a M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine. The thesis is deposited at Jimma University Library to be made available to borrowers under the rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of academic degree, diploma or certificate. Brief quotations from this thesis may be made without special permission provided that accurate and complete acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is for scholarly interest. In all other instances, however, permission must be obtained from the author of the thesis.

Name: Yohannes Atnafu

Signature: _____________

Place: Jimma University

Date of Submission: ___/03/2020 G.C.

Plant Sciences (Horticulture)

LIST OF ACRONYMS AND ABBREVIATIONS

AARC	Ambo Agricultural Research Centre
BECC	Bayer Ethiopia Chemical Company
CSA	Central Statistical Agency
EIAR	Ethiopian Institute of Agricultural Research
EIL	Economic Injury Level
ETL	Economic Threshold Level
GIMA	Government of India Ministry of Agriculture
MARC	Melkasa Agricultural Research Center
NAL	Nufarm Australia Limited
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
UNCTAD	United Nations Conference on Trade and Development
WMS	White Mango Scale

BIOGRAPHICAL SKETCH

The author, Yohannes Atnafu, was born in Gondar, Amhara Regional State in 1989. He attended elementary education at Meseret primary school from 1997 to 2003 in Gondar and Mekane Eyesus secondary and preparatory school from 2004 to 2009 at Estie. In 2010, he joined Mekelle University and graduated with B.Sc. degree in Horticulture in June 2012. After graduation, he was employed by Addis Ababa Trade and Industry Office in August 2013 where he worked as a trade marketing officer and in 2014 he joined Ethiopian Institute of Agricultural Research (EIAR) at Ambo Agricultural Research Center (AARC) where he worked as a junior researcher. He joined Jimma University in 2017 to pursue a postgraduate study in Horticulture.

ACKNOWLEDGMENTS

First and foremost, I would like to praise and glorify the supreme Almighty Grace God for providing me with the strength and patience to complete the study.

I would also like to express my deepest and heartfelt thanks as well as my most sincere appreciation and gratitude to my major advisor Dr. Wakuma Bayissa and my co-adviser Dr. Belay Habtegebriel for their keen interest, dedication and supervision, for motivating and scientifically supporting me during the whole period of the study. I also thank them for genuinely and constructively criticizing my work from the time of inception of the research work up to its completion and thesis write-up.

I would like to express my gratitude to Dr. Weyessa Garedew for his supports in data analysis. I also thank Mr. Dawit Melisie, Tekalign Gadissa and all AARC Entomology laboratory staff members to support during the field and laboratory work. I would like to take this opportunity to say warm thanks to my best friends Habtamu Eshetie, Mezgebu Debelo, Gemech Kebede and Dinberu Kebede who have been so supportive along the way of doing my thesis.

Finally; I would like to thank EIAR and AARC for offering me this opportunity and financial supporting and Jimma University to offering me the study opportunity.

TABLE OF CONTENTS

LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

LIST OF THE APPENDIX

PAGE

ABSTRACT

*Insect pests are among the most important biotic factors limiting mango production in Ethiopia. White mango scale (*Aulacaspis tubercularis *Newstead) is an invasive pest currently posing series problem on mango in the country. There are limited and/or no effective control options available for the management of the pest. Thus, it is important to investigate various pest management options as standalone and/or in an integrated pest management approach. The objective of this study was therefore, to evaluate different insecticides, detergents, mineral oils and pruning for the management of white mango scale at Raj agro industry LTD farm on established trees. Eight insecticides and un-treated (control) were used as treatments with and without pruning for evaluation the efficacy of different insecticides and pruning. Thus there were a total of 18 combination treatments. Randomized Complete Block Design in factorial were used and replicated three times. Mineral oil, ordinary vegetable oil, white oil (the mixture of oil and liquid soap) and pruning were used alone and combination as treatments for evaluation of different oils, detergent and pruning. In total 11 treatments including untreated (control). The treatments were arranged in a randomized complete block designs and replicated three times. Twelve leaves were randomly picked from the lower branch of each tree in four cardinal directions. The number of crawler, male and female white mango scale were counted using a stereoscopic microscope. Movento 150 OD (1.57) after first application and Dimethoate 40% EC (2.3) after second application were found effective in management of white mango scale for efficacy of different insecticides and pruning. Pruning also significantly decreased the number of WMS after first (23.83) and second (14.66) application compared to non-pruned treatments. Mineral oil plus white oil showed lower number of white mango scale after first and second application of treatments (15.97) and (8.2) respectively for evaluation of oils, detergent and pruning after first application. Private companies, investors and smallholders and local farmers could be advised to use mineral oil (50ml/15L/3tree) plus white oil (31.5ml/15L/3tree), pruning, Dimethoate 40% EC (50ml/15L/3tree) and Movento 150 OD.*

Key words: Mango, white mango scale, Insecticides, oils, detergent and pruning.

1. INTRODUCTION

Mango, *Mangifera indica* L*,* is one of the most important fruit crops which belongs to the family of Anacardiaceae, and consumed in fresh and processed form worldwide (Banerjee, 2011). The fruit is an important cultural and religious symbol considered as "king of fruits" (Mukherjee and Litz, 1997). It has an attractive color, sweetness, excellent flavor, delicious taste, high nutritive value and health promoting qualities. It has high amount of sugar, protein, fats, and all known vitamins (Nabil *et al.,* 2012). It is also an excellent source of dietary antioxidants, such as ascorbic acid, carotenoids, and especially phenolic compounds (Ma *et al.*, 2011). Mango is also used in different parts of the world as animal feed, poultry diet, in Ethno-pharmacology and various chemical industries (Wauthoz *et al*., 2007; Kayode and Sani, 2008; Nwinuka *et al.,* 2008).

Mango is the most important fruit in Asia, and among the total production of major fruit crops in worldwide currently ranks fifth after bananas, citrus, grapes and apples (FAO, 2009). It is cultivated in more than 85 countries in the world with total production area coverage around 3.69 million hectares. In the year 2009, the world total production of mango was around 35 million ton per year globally (FAO, 2009). The productivity of mango has increased by over 100% worldwide from 1971 to 2002 and the production was estimated to be around 25.75 million tons in 2002 (FAO, 2002). Pertaining to its global demand, mango play significant role in foreign currency generation and accordingly, its production has been on a rise from time to time (UNCTAD, 2016). Both domesticated and wild fruit species are grown in Sub-Saharan Africa by farmers and small scale farmers for its significance to health, ecological benefit and revenues (Weinberger and Lumpkin, 2005).

In Ethiopia mango has significant importance with a potential for domestic and export markets and industrial processing (Honja, 2014). In the year 2017 the Central Statistical Agency (CSA), reported that Ethiopia has a total area of 1.08 million km^2 for fruit production and the total fruit production area in Ethiopia is around 107,890 hectares. Bananas, Mangoes Avocados, Papayas, and Oranges took up 67.94%, 13.21%, 8.20%, 6.36% and 2.61% of the fruit production, respectively. Around 1,857,387 households contribute to mango production and about 185,739 tons of mangos produced per year from 15,413.76 hectares (CSA, 2017). The contribution of mango is about 14.29% of the area allocated for fruit production and it holds 13.21% of quintals of fruits produced in Ethiopia (CSA, 2017).

Mango production is constrained by different factors such as diseases and insect pests. Huge losses of Mango have been incurred by factors such as poor agronomic practices, damage by resident and invasive pests, unavailability of high quality planting materials and poor post-harvest practices in Ethiopia (Ayalew *et al*., 2015). Insect pests are among the most important factors limiting mango production in Ethiopia and elsewhere in the world. The most important insect pests of mango are stone weevil (*Sternochetus* spp.), mealy bugs, fruit flies, white mango scale, and mites (Griesbach, 2003; FAO, 2010). White mango scale is the most important insect pests and reported to have a damaging effect on mangoes in many parts of the world including Ethiopia (SRA, 2006; Germain *et al*., 2010; Abo-Shanab, 2012; Ofgaa and Emana, 2015).

The white mango scale, (*Aulacaspis tubercularis* Newstead) is distributed in many mango-growing countries and it feeds on more than 40 plant species (Kondo and Muñoz-Velasco 2009). White mango scale presents an economic problem on mangoes in South Africa, Australia, Italy, East & West Africa, North & South America and the Caribbean countries (Daneel & Joubert, 2009; Urias *et al*., 2010). In Ethiopia occurrence of white mango scale was reported for the first time at a private farm called Green Focus Ethiopia LTD. in East Wellega Zone in August, 2010 (Mohamed *et al*., 2011).

White mango scale insect affects the commercial value and export potential of fruits. It damages mangoes by feeding on the plant sap of leaves, branches and fruits, causing defoliation, drying up of young twigs and, poor blossoming. In nurseries, infestation at early stage retards growth of seedlings (Hodges and Hamon, 2006; Abo-Shanab, 2012; Manners, 2016). During hot dry weather young trees are mostly vulnerable to excessive leaf loss and death of twigs. The mature fruits are heavily infested premature fruits drop and they become small in size with insufficient juice and total death of the plant can become evident if infestation occurs at nursery stage (Abo-Shanab, 2012).

White mango scale infested areas on leaves turn pale green or yellow and ultimately die. Heavy infestation can kill leaves and branches (Abo-Shanab, 2012). Currently mango production in

Western Ethiopia is highly constrained by white mango scale and little information is available on the management option of this pest. Some chemical pesticides such as: Imidacloprid 35% SC and Thiamethoxam 25 WG were registered for control of the white mango scale, and Dimethoate 40% EC was registered long time ago as an effective pesticide against other scale insect on mango and red scale on citrus in Australia and India (Manners, 2016; GIMA, 2012). Lambda cyhalothrin 17.5% SC was registered for common scale insects of mango in Australia and India (NAL, 2004; Parakash and Patil, 2018). However, little efforts have been made on chemical screening and registration of chemical pesticides to combat white mango scale in Ethiopia. Movento 150 OD, Methidathion 400 EC and Folimat 500 SL were recommended in Ethiopian conditions and reported to reduce the number of white mango scale (Ayalew *et al.*, 2015; Djirata *et al*., 2016). Combined use of different options such as cultural practice, chemical pesticides and other options can help reduce the cost and residue problem of chemicals (Smith, 2005). Efforts made in investigating non-chemical options remain scarce. Thus, it is important to investigate the level of control that can be achieved by using non-chemical pesticides (mineral oil and detergent) and cultural practices as well as new chemical pesticides. Therefore, this study was initiated to address some of the knowledge gaps.

Objectives

General objective

To develop effective pest management for the white mango scale (*Aulacaspis tubercularis* Newstead).

Specific objectives

To evaluate the effectiveness of pruning practice alone and combined with other chemical and non-chemical pesticides to managing white mango scale at field condition.

To compare the efficacy of different oils and detergent in managing white mango scale at field condition.

To evaluate the efficacy of selected chemical insecticides against white mango scale at field condition.

2. LITERATURE REVIEW

2.1. Economic Importance of Mango and White mango Scale

Mango is a highly seasonal tropical fruit, very popular among millions of people in the tropics. It also occupies a prominent place among the best fruits of the world (Honja, 2014). The mango industry in Ethiopia is in its infant stage. However, mango is grown in many parts, especially in the Rift Valley, western and southwestern parts of the country. The national research system has developed a number of varieties but is not widely spread. Experiences from other countries in growing this crop will therefore contribute to the success and widespread of this fruit (Honja, 2014). Mango is one of the most important fruits produced by the rural communities of West and Eest Wollega Zone of the Oromia Regional State. It is an important fruit produced for income-generation in the area and contributes to the country's economy through feeding the local community, ecological balance and foreign exchange earnings (Duressa, 2018). Many resource poor farmers sell their mango fruits to the local markets without further processing it and use the money to purchase livestock, agricultural inputs, food crops, learning materials for their children and other household items. Mango is considered as an important element in certain sociological aspects in some parts of Ethiopia. In Ethiopia mango is considered as an important element in certain sociological aspects in Benishangul-Gumuz Regional State and other parts of Western Ethiopia, and mango tree is used as a shade for livestock and conference hall for local people, during hot weather conditions (Djirata *et al*., 2016).

Mango is produced in Ethiopia at small scale level, primarily for family consumption and local markets, whereas very few large farms produce mango for local and export markets (Alemayehu *et al*., 2014). Some companies are producing fruit juices in Ethiopia, found in Sebeta, 24 km Southwest of Addis Ababa of which a mango juice (Wiersinga and Jager, 2009).

However, recently, the production of mango has been constrained by the white mango scale (Mohammed *et al.,* 2012). This insect pest is an important biotic factor that causes damage to the fruits resulting in serious economic losses and making the fruits of poor quality (Figure 1). In recent years farmers have been uprooting mango trees from their farms because of damage by the white mango scale (Manners, 2016). Starting from the year 2012 the pest was causing an extreme reduction of mango production and productivity. There was a total failure in mango production in year of 2014 and they cultivate other crops the land under mango trees to (Terefe *et al*., 2014).

The white mango scale is a pest that is present all year round-with overlapping generations and damages the shoots and leaves of the plant not only by feeding on the parenchyma sap but also by producing toxic saliva (Miller *et al*., 2005). Infested areas on leaves turn pale green or yellow and ultimately die. Heavy infestation can kill leaves, branches and attack of the pest on mango fruit causes development of conspicuous pink blemishes around its feeding sites, and as a result export potential of the fruits and their commercial value are greatly affected (Joubert *et al*., 1999; Hodges and Hamon, 2006; Abo-Shanab, 2012).

Figure 1 Unmarketable mango fruit damaged by white mango scale at Raj agro industry LTD. farm

2.2. Distributions of White Mango Scale

The white mango scale occurs widely throughout the tropical and sub-tropical areas of the Americas, Africa, Asia, Australia and the Pacific (Malumphy, 2012; Stocks 2013).

According to Hodges and Hamon (2016), distribution of white mango scale in the world is classified in different zones, such as: **Afrotropical:** Ghana, Kenya, Madagascar, Mauritius, Mozambique, Reunion, Rodriques Island, South Africa, Tanzania, Uganda, Zanzibar and Zimbabwe; Australasian: New Caledonia and Vanuatu (New Hebrides); Neotropical: Aruba, Bermuda, Brazil, British Virgin Islands, Colombia, Dominican Republic, Grenada, Guadeloupe, Martinique, Puerto Rico & Vieques Island, Saint Croix, Trinidad and Tobago, Trinidad, U.S. Virgin Islands and Venezuela; Oriental: China (Guangdong) (Kwangtung), Hainan, Sichuan (Szechwan), India, Karnataka, Indonesia; Malaysia, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand; Palaearctic: China, Egypt, Iraq, Israel, Italy and Japan.

In Ethiopia white mango scale was first recorded in 2010 in Western Ethiopia East Wollega Zone of Oromia region in Green focus Ethiopia private farm at Loko in Guto Gida district (Mohammed *et al*., 2012). The pest has been spreading too many other neighboring districts, including the mango production belt in the area (Mohammed *et al*., 2012; Ayalew *et al*., 2015).

The distribution of white mango scale in Western Oromia East Wollega was quickly spreading from one mango growing area to another and now distributed to all districts (Terefe *et al*., 2014). Severity status of white mango scale in mango orchards was studied by Fita (2014), in five districts of two zones: Guto Gida, Gobu Sayo and Diga districts of East Wollega and Gimbi and Mana Sibu districts of West Wollega Zone in the western part of Oromia Regional State. Results showed that all the districts were infested by white mango scale (Fita, 2014). In central rift valley more than seventeen districts, over 200 hectares of mango orchard infested by white mango scale recorded in 2014 (Ayalew *et al*., 2015). During 2016/17 severity of White Mango Scale, in South Western part of Ethiopia was high to very high except some districts. In Jimma town, all part of East Wellega, Arjo, Buno Badele, Benshangule (Asossa, Bambasi and Hamosha districts), Bench Majii, Majang, Shaka and Gambela town were recorded from mid to very high infestation of white mango scale (Teshale *et al.,* 2019).

2.3. Biology of White Mango Scale

White mango scale, is a circular, flat, thin and wrinkled insect. Exuviae lie near the margin and are yellowish-brown, with a median black ridge, forming a dark distinct median line. Males are small, white, with their sides nearly parallel and distinctly tricarinate. On slide-mount: with angular prosoma; body is widest at prominent lateral tubercles, almost level with anterior spiracles; posterior spiracles are usually associated with spiracular pores; gland spines and macro-ducts are absent from thorax and head (Soysouvanh and Hong, 2016). General appearance of the white mango scale is that newly hatched nymph is very small, elongate, oval and totally bare of any wax secretion and the crawler moves about until it discovers a suitable place to settle on. After settling, fine threads of wax which appear cottony start to be secreted and exude from the body until, until the insect is completely covered with the white filament which is commonly referred as ‘‘white cap’’. The male crawlers settle, often near females, in groups of 10 to 80; these groups are conspicuous due to the white scale covers (Halteren, 1970).

Depending on temperature females lay 80 to 200 eggs and crawlers move to feeding sites settling within 24 hours after hatching. Male crawlers settle in groups close to females and female crawlers settle randomly. Up to 80% of crawlers become males (Halteren, 1970). In nurseries, infestation at early stage retards growth of seedlings. During hot dry weather young trees are mostly vulnerable to excessive leaf loss and death of twigs. The mature fruits are heavily infested premature fruits drop and they become small in size with insufficient juice and total death of the plant can become evident if infestation occurs at nursery stage (Abo-Shanab, 2012).

Adult scales can be found in masses on the upper and underside of leaves and occasionally on the fruits. The female is white and oval and about 2 mm in diameter and has a characteristic black spot (the puparium, which is incorporated into the waxy layer). Females are only occasionally seen, since the males are more prominent. They are white and about 1 mm in length and distinctly tricarinate. The crawlers are deep bright red. The life cycle takes between 35 – 40 days for females and 23 – 28 days for males (Halteren, 1970). Adult female with swollen, angular or quadrate prosoma; body widest at prominent lateral tubercles, almost level with anterior spiracles; posterior spiracles usually associated with spiracular pores; gland spines and macroducts absent from thorax and head. Pygidium with median lobes zygotic, without any setae or gland spines between their bases; abdominal segment VI bearing 1 or 2 submedian macroducts on each side; and pore prominences between pygidial lobes well developed. Often on mango; does not feed on grasses. In life, scale cover of adult female approximately circular, white and transparent, with dark, oval exuviae. Scale cover of male smaller, rectangular, white with three raised longitudinal ridges; exuviae **(**New Zealand, 2018; http://www.padil.gov.au:80/maf border/Pest/Main/141387**).**

2.4. Ecology of White Mango Scale

Weather is an important parameter that affects white mango scale distribution, abundance and their management. According to Dharmendra *et al*. (2014) favorable weather condition for high pest infestation ranges between 24-35°C and relative humidity 70-95% in both mango orchards. Abo-Shanab (2012) reported a significant positive relationship between daily mean temperature and relative humidity, and recorded population density of *A. tubercularis.* On the other hand, the author reported a significant negative relationship between wind speed and dew point, and population density of *A.tubercularis* which may be due to transference of insect crawlers and early nymphal instars by the wind to another plants and/or places.

In a maximum day time temperature of 26°C and night time minimum of 13°C white mango scale can produce five to six generations per year (Miller and Davidson, 2005). According to Sayed (2012), the total population of WMS had maximum value 1006.89 individuals/leaf on June 15th at 15.2-28.4^{0}C and 56.8% R.H. The lowest level was in mid-December (39.80 individuals / leaf) at 15.0-22.2^{0}C and 55.6% R.H. The mean numbers of nymphal, adult female, per sample unit were the highest in mid-March as 343.75 and 147.66, individuals, respectively. The gravid female and prepupae and pupae stages reached their maximum as 129.94 and 694.31 on July 15th and April 15th, respectively. The lowest densities of nymphs and gravid female were 12.33 and 5.33 individuals on mid-December, whereas the least values of adult female and pre-male 3.94 and 15.49 were observed in early September and mid-November, respectively. The total population had maximum value of 1095.65 individuals on April 15th at 12.3-23.8^{0}C and 57.20% R.H. The lowest total population (58.30 individuals) was observed during Dec. 15th (38.72 individuals/leaf) at 15.2-21.8^{0}C and 56.3% RH. This pest was higher abundance throughout the period extended from mid-February up to mid-September, while it was lower in abundance from early October up to early February (Sayed, 2012).

White mango scale females and males were randomly distributed on leaves, stems, and fruit in mango orchards under organic and conventional management, although males were grouped in colonies of a few individuals to more than 100, which eventually allows them to occupy the entire leaf in depending on the season (Urías-López *et al*., 2010).

2.5. Signs and Symptoms of White Mango Scale

In white mango scale fertilization takes place and the tiny crawlers hatch out and move about until they glue themselves to the part of the plant where they develop and remain sucking the juice of the plant under their armors (Louw *et al*., 2008; Goble *et al.,* 2012). A leaf penetration pattern of *A. tubercularis* revealed that it can penetrate not only cell wall but also the lignified xylem materials leaving behind a reddish mass which was believed to have been phenolic acid. From infested mango leaves the slices followed the stylet bundle (SB) penetration path through the leaf from the piercing site on the leaf epidermis. Including oblique and parallel orientations in relation to the leaf surface, the SB changed directions several times depend upon entering the spongy mesophyll (Juarez-Hernández *et al*., 2014). Histological evidence indicates that after penetrating the coriaceous cuticle and epidermis, the white mango scale SB explores the interior of mango leaf tissue, including vascular bundles, by changing its path yet maintaining most of its pathway in the mesophyll (Evans *et al*., 1985). The female feeds mainly on the mesophyll cells as it pierces them from the path of SB without causing their collapse. The exploration pathway of the SB through the leaf tissues is mostly intracellular, and the SB is capable of piercing the lignified cell walls of vascular bundles (Juarez-Hernández *et al*., 2014).

Scale insects feeding on young, growing tips can cause distorted foliage. Feeding on leaves may cause them to yellow and plants may appear water stressed. Heavy infestations can cause stems and branches to dieback; unhealthy plants may die. Scales present on fruit may cause them to be blemished or distorted, particularly if infestations occur when fruit are developing. A small number of species induce ornate galls in their host plants. As mentioned above, honeydew often causes the growth of black sooty mold, which can be extremely unattractive and may cause plants to be unsalable. Black sooty mold is superficial and can sometimes be removed with some fungicide applications, but is only recommended after scale insects have been eradicated (Manners, 2016).

2.6. Management of White Mango Scale

The widespread and rapid establishments of the pests in orchards or gardens require immediate changes in integrated pest management (IPM) program as promising prospect. White mango scale can be managed by using resistance cultivar, cultural, biological, chemical and integrated pest management methods (Sarwar *et al*., 2014).

2.6.1. Cultural control

The goal of cultural control is to make the environment less favorable to pest development and reproduction. Proper fertilization, pruning, and irrigation maintain plant vigor, promote plant tolerance to pest damage, and reduce sap-sucking insect population growth (Dreistadt; 2007; Kabashima and Dreistadt, 2014).

Mulching is one of the controlling mechanisms of WMS especially in the young mango trees. Planting cover crops especially in mango orchards before fruit production starts can reduce population of white mango scale. Plugging of orchard after harvest to expose hibernating adults, reduce, infestation levels. Pruning is effective in removing infested plant tissues and reducing populations of scale (Kabashima and Dreistadt, 2014).

There are different ways of pruning such as; Formative pruning - is done in the first years of the young tree to guide the tree into the desired shape. In the first year, when the trees are about 1 m from the ground, cap the seedling in order to encourage side branches (3 to 4 well branches). Thereafter, every second flush of leaves should be removed. Structural pruning - should be done for proper maintenance of the trees. The height of the trees should be controlled to about 3.5 m in height and at this stage, all branches at knee level (about 0.5 m) should be pruned (skirt pruning). Any dead branches and sucker branches should be removed to allow more sunlight through the canopy to the ground under the tree. This should be done every year in order to maintain the tree at 3.5 m and develop a suitable canopy density (FiBL, www.fbl.org , 2011).

Post-harvest pruning is an effective control measure and also helps the penetration of chemical sprays through the tree canopy (Terefe *et al*., 2014). The authors suggested other possible cultural control measures outlined such as: quarantine new plants and treat before placing them with established plants; spot treat with insecticidal soap if needed, taking care to cover all crack cervices and other possible hiding places: - water + oil treatments: Application of a garden hose with water in a hard spray and washing off white scales can be removed following the application of oil:- Wash plants with soapy water (2 teaspoons mild detergent per gal of Water) and a soft cloth. When plants are lightly infested, kill scales by rubbing then off with your fingers, if possible.

2.6.2. Biological control

Biological control is the utilization of natural enemies to reduce the damage caused by noxious organisms (pests) to tolerable level (Djirata *et al*., 2016). The most known natural enemies used as bio-control agents in frequency of their use include parasitoids (parasitic wasps and flies) predators (some insects, spiders and predatory mites) and pathogens (fungi, protozoa, bacteria and virus) (Mills and Daane, 2005). There are a number of natural enemies that can manage scale insects including commercially available predatory insects and naturally occurring parasitoid wasps and predators. There are also a range of fungi and bacteria that may infect and kill scale insects, although these are less likely to substantially reduce populations unless they become very abundant. Almost all pesticides will negatively impact beneficial insect populations (i.e. predators and parasitoids). It is recommended to seek advice from the biological control agent producer prior to releasing a predator for the first time so that their release is optimized. If pesticides have been applied, ensure that a sufficient time period elapses before releasing beneficial insects (Eagling, 2009). This pest *A. tubercularis* is under good biological control in most other mango producing countries and therefore it was decided to introduce an exotic biological control agent and try to establish it in different mango producing areas. Both the parasite and predators were successfully augmented, released in to mango orchards and became well established (Daneel and Dreyer, 1997 and 1998).

The predatory thrips *Auleurodothrips fasciapennis* Franklin and the parasitoid *A. citrinus* were reported as the most important bio-control agents of *A. tubercularis* in South Africa

(Labuschagne, 1993). According to Sayed (2012), *Cybocephalus sp*., *Chrysoperla carnea* (Stephens), *Chilocorus bipustulatus* (L.) and predacious mites are predators of *A. tubercularis* and *Aphytis sp*., *Aspidiotiphagus citrinus* (Craw) and *Encarsia sp*. are parasitoids of *A. tubercularis.* With regard to the collected numbers of predators the *C. sp*., was dominant predator on mango trees represented by 35.1% followed by *C. carnea* (23.5), *Ch. bipustulatus* (21.4%), while the predacious mites was the lowest species represented by 11.8%. The overall mean total population of *A. tubercularis* predators throughout two years (2010 and 2011), showed three peaks that were estimated by 0.90, 0.91 and 0.94 individuals/leaf could be detected on May 1st, July 1st and August 15th, respectively. The study of *A. tubercularis* parasitoids on infested mango in the presence parasitoids, *Aphytis sp*. was the common parasitoids represented 40% followed by *Encarsia sp*., (34%) and *A. citrinus* (26%).

The larvae of the ladybird beetle *Chilocorus* sp. (Coleoptera: Coccinellidae) infested with white mango scale and they were found feeding on both male and female white mango scales. When feeding, the larvae easily destructed coat of the male mango scale and reached it, whereas they forcefully pushed their heads inward and partly opened up cover of the female, captured and chewed it. In all instances of observations the presence of the larvae was associated with colony of white mango scales (Djirata *et al*., 2016).

2.6.3. Host plant resistance

High costs, difficulty in application methods, environmental and ground water pollution hazards of chemical pesticides has led to more emphasis to non-chemical or alternative methods of scale insect management. Plant insect resistance mechanisms are divided into three categories: non-preference, antibiosis and tolerance (Painter, 1951). Resistant cultivars are economically feasible and environmentally safe method for controlling various pests and diseases including the white mango scale.

The term non-preference has subsequently been replaced by antixenosis (Kogan and Ortman, 1978), because non-preference refers to the insect and this is incongruous with the notion of resistance being a property of the plant. Antixenosis is the resistance mechanism employed by the plant to deter colonization by an insect. Insects may orientate towards plants for food, oviposition sites or shelter but certain plant characteristics may be a biochemical or morphological factor, or a combination of both may deter them. Plants that exhibit antixenotic resistance would be expected to have reduced initial infestation and/or a higher emigration rate of the pest than susceptible plants. Antibiosis in contrast to antixenosis is the mechanism by which a colonized plant is resistant because it has an adverse effect on an insect's development, reproduction and survival. These antibiotic effects may result in a decline in insect size or weight, an increased restlessness, poor accumulation of food reserves affecting the survival of hibernating or aestivating stages, or have an indirect effect by increasing the exposure of the insect to its natural enemies (Singh, 1986). Plant tolerance can be described as the extent to which a plant can support an insect infestation without loss of vigor and reduction of crop yield. Beck (1965) does not consider that tolerance falls within the definition of resistance. Plant tolerance is usually taken to mean that when two cultivars are equally infested the less tolerant one has a smaller yield. At the plant physiological level the loss of tolerance is due to an abnormally heightened response to infestation, at the epidemiological level tolerance is considered a component of resistance (Robinson, 1976).

In Kenya, Samuru and Kimani district the levels of white mango scale infestation on mango was varied among some of the cultivars. At Samuru Vandyke was more infested than Apple mango. Kent mango was found to be the most infested of all mango cultivars at Kimani. Apple mango was among the least infested cultivars in both sites (Djirata *et al*., 2016).

However, few studies investigated resistance or tolerance of various host plant species or cultivars to soft scales in the field (Camacho and Chong, 2015). Host plant resistance to scale insects is likely conferred by an interaction between plant genetic, physiology, and biochemistry (McClure, 1985). The varieties of mango Alfa, Espada Stahl and IAC111 were field resistance to fruit flies compared to Tommy Atkins was highly susceptible to fruit flies. Under artificial infestation in cage conditions however, Alfa maintained its field resistance and Espada Stahl and IAC111 had their resistance broken and became as susceptible as Tommy Atkins (Rossetto *et al.,* 2006). According to Karar et al., (2012) Insects are more attractive to dense canopy structure in mango orchards. A necessary requirement for leaf size and shape to evolve in response to attack by insects is that insects must respond to leaf morphology. Leaf size extremely affects invasion of sucking insects on host crops. Mango varieties Fajri, Sindhri, Malda, Dusehri and Anwar

Retaul were narrow shaped with reduced leaf width which ultimately resulted in low mealy bug abundance in these crops than other genotypes.

2.6.4. Chemical control

Scale insects are difficult to manage using pesticides alone. If pesticides are to be used to manage scale insects it is recommended to apply contact products only when there is a high proportion of crawlers present. Crawlers are very susceptible to many pesticides, including oil based products. If high populations are present a systemic product will probably be required (Manners, 2016). Insecticides registered for soft scale management can be broadly categorized into contact and systemic insecticides. Systemic insecticides, which include members of organophosphates, neonicotinoids, tetramic acid derivatives, and diamides, function as contact insecticides when applied as topical sprays directly on the scale insects. When applied as soil drench, soil injection, basal trunk spray, trunk injection, granular broadcast, and pellet broadcast, systemic insecticides are absorbed by plant tissues and trans located to the canopy (Frank, 2012).

Typically, the application is made just before crawler emergence to ensure the highest concentration of active ingredients in the plant tissues. Although systemic insecticides have the benefits of greater flexibility and residual longevity, recent studies suggest that neonicotinoids should be used carefully because of their potential impact on pollinator health (Cowles, 2014; Pisa *et al*., 2014; Johnson and Corn, 2015) and their implication in spider mite outbreaks (Szczepaniec *et al*., 2011, 2013; Szczepaniec and Raupp, 2013).

According to Smith *et al*., (1997), petroleum sprays at a rate of 1 % are recommended for the control of hard scales in Australia. Application of systemic or growth regulators helps to prevent population increase. Pre-harvest applications to prevent the scale insects build up during harvest. High volume (1200L/ha) cover sprays after pruning with mineral oils and methidathion depending on scale activity. Chloropyrifos, methidathion, Dimethoate 40%EC, (Howard, 1989), Diver and CAPL2 oils have been found successful in reducing the population of white mango scale (Abo-Shanab, 2012; Terefe *et al*., 2014). According to Manners (2016), active ingredients registered against scale insects relevant to Australian mango nurseries, include; Carbaryl, Chloropyrifos, Diazinon, Dimethoate, Methidathion, Imidaclopride, Pyriproxyfen, Buprofezin, Paraffinic oil and Sulfer.

The studies of Ayalew *et al*., (2015) reported to the Movento was effective pesticides against WMS. According to Djirata *et al*., (2016) Folimat 500SL was found to be the most effective of the three insecticides and the best period for application of insecticide for the control of white mango scale is from April to June, when white mango scale, in general and the crawlers in particular, are more abundant in western Ethiopia.

2.6.5. Integrated pest management

An integrated pest management alternative could be applied that would consist of a combination of pesticides, cultural practices and the use of biological control agents (Meyerdirk, 2002). And also Pesticide application in mango orchards resulted in high mortality of endemic parasitoid (Labuschagne and Pasques, 1994; Daneel and Drayer, 1998). Integrated pest management is a pest management philosophy that utilizes all suitable pest management techniques and methods to keep pest populations below economically injurious levels. IPM is a monitoring and decision-making process for selecting the most appropriate, cost effective, compatible method of managing pests. It minimizes pest damage with minimal disturbance to the natural balance of the agro-ecosystem and minimal risk to human health. It does this by decreasing the net chemical pesticide inputs to agriculture. This eventually minimizes dependence on chemical pest control (Varela *et al*., 2006). For mango growers to adopt IPM strategies, they must be compatible and economically viable so that when properly implemented and precisely managed, they can jointly reinforce production goals of immediate economic gain and long-term sustainability (Sullivan *et al.,* 2000; Vayssières *et al*, 2009b). Conceptually, IPM falls between conventional and organic agriculture. The introduction of IPM presents a feasible and cost effective alternative to conventional agriculture by significantly lowering the costs of chemical pesticide use as well as an alternative to organic agriculture which in many cases, has been demonstrated not to substantially affect productivity (Kumari *et al*., 2014). In developing countries, IPM strategies are often the exception rather than the norm because of their higher labor demands and this is generally the reason why they are practiced on a small scale. Generally, IPM approaches are based on restoring the natural balance between pests and their predators in ecological systems. Where such IPM approaches are applied, it is possible to develop a profitable fruit industry because most of them are pest-specific and are influenced by host-plant relationships and the crop ecosystem.

According to Djirata *et al*., (2016) integrated approaches to managing WMS was effective in Ethiopia and Kenya. The study was revealed that Cultural practices such as cyclic pruning and consistent scouting for white mango scale infestation and removal of infested parts are essential management practices. Some improved mango varieties like Apple mango was less susceptible to white mango scale infestation in central and eastern Kenya. *Chilocorus* sp. was found preying ravenously on live white mango scale, signifying its association as a native predator with the exotic white mango scale. White mango scale has been introduced to Ethiopia, recently and its origin and related natural enemies should be conducted for the designing and implementation of classical biological control. The population of WMS is above the economic injury level insecticide should be implemented and Folimat 500SL was found to be the most effective insecticides against WMS.

3. MATERIALS AND METHODS

3.1. Descriptions of the Study Area

3.1.1. Field experiment

The study was conducted on infested mango orchards in western Ethiopia. Mango orchards and homestead mangos in the Oromia Regional State of Eastern Wellega Zone in Guto Gida district Uke administrative area at the Indian private farm were used for this experiment. The Indian private farm of Raj agro industry is situated 35 km North of Nekemte, located at 09°56.574’ N and 034°34.704’E and has an elevation of 1516 meters above sea level (Google map, 2019).

3.1.2. Laboratory experiment

Counting of crawler, male and female from collected leaf samples was conducted at Ambo Agricultural Research Center (AARC) entomology laboratory. This center is situated 126 km West of Addis Ababa and is located at $8^o57'$N latitude, $38^o7'$E longitude with an altitude of 2200 meters above sea level. The center receives an average annual rainfall of 1050 mm with average minimum and maximum temperatures of 10.4°C and 26.3°C, respectively, and relative humidity of 64.4% (AARC metrology station, 2019).

3.2. Experimental Materials

Twelve years old Kent variety mango trees with high and similar infestation level of white mango scale visually were used for the field experiment. Kent is one of the most important mango varieties in Ethiopia and registered in 2007 by Melkasa Agricultural Research Center (MARC) (EIAR, 2018 http://www.eiar.gov.et/marc/index.php/anrl-research/crop-research).

The different insecticides were obtained from Bayer Ethiopia Chemical Company (BECC) in Addis Ababa. Commonly used detergents and mineral oil were bought from the local market (Table 1).

Table 1: Description of insecticides and oils used for the study

No.	Common name	Trade name	Application rate ha^{-1}	Source
	Different insecticides			
1	Thiamethoxam 25% WG	Thiamethoxam	4.1kg	BECC
2	Dimethoate 40% EC	Dimethoate	3.4L	"
3	Imidacloprid 35% SC	Confidence 35% SC	0.6L	"
4	Spirotetramat 150g/L	Movento 150 OD	4.1L	"
5	Imidacloprid 100g + Beta cyflothrin 45g/L	Thunder 145 OD	0.6L	"
6	Spirotetramat 15% + Thiamethoxam15.5%	Kuto	0.9L	"
7	Spirotetramat	Toran 240	1.63L	"
8	Imidacloprid +Lambda cyhalothrin 17.5% SC	Perfecto 17.5% SC	1.4L	"
	Different oils			
1	Petroleum oil	Mineral oil	10.2L	Local market
2	Ordinary vegetable oil	Vegetable oil	10.2L	"
3	Liquid soap and oil mix	White oil	1.7L and 0.44L	"

3.3. Treatments and Experimental Design

3.3.1. Evaluation of different insecticides and pruning

The Thiamethoxam 25% WG (systemic) was applied to the soil as a drench and the rest of the insecticides were foliage sprays using a motorized sprayer. Dimethoate 40% EC, Confidence 35% SC, Movento 150 OD, Kuto, Toran 240, Thunder 145 OD and Perfecto 17.5% SC were recommended for scale insects (http://cibrc.nic.in/; http:// era.daf.qld.gov.au/2208/6/005-ipm.pdf; Bahati, 2010 and Prakash and Patil, 2018). Pruning were done using a hand held saw to remove old and dead branches and twigs to open the canopy and in order to allow entry of adequate sunlight to the lower canopy of the mango trees (Terefe *et al*., 2014). Controls were sprayed with equal amount of water used for spraying the mango trees in each of the treatments.

Treatments were applied twice at flowering stage in January and near harvesting time in April when the white mango scale (WMS) population was expected to be high or at its peak.

Eight insecticides and un-treated, with pruning (pruned) and without pruning (non-pruned) were used as treatments for the evaluation of insecticides. Thus there were a total of 18 combination treatments (Table 2). Randomized Complete Block Designs in Factorial were used and replicated three times. One mango tree was used as one plot and 54 mango trees were used for the experiment.

Twelve leaves were randomly picked from the lower branch of each tree in four cardinal directions prior to treatment application to count and estimate the level of infestation by the white mango scale. The leaves were kept in plastic bags and transported to AARC entomology laboratory for counting. The number of crawler, male and females of white mango scale were counted using a stereoscopic microscope. The adult female has circular armor, flat, thin and often wrinkled. Male armors are small, white, sides nearly parallel. Crawlers were deep bright brick red. Mean number of insects from post treatments application were used to assess the efficacy of the insecticides.

The number of white mango scale per 12 randomly selected leaves was counted in each replicate and mean numbers obtained after each application. The percent of white mango scale reduction was calculated by:

$$\text{Percent of reduction} = \frac{\text{Original No.} - \text{New No.}}{\text{Original number}} \text{X}100$$

Where Original No. is the mean number of WMS before treatment application and

New No. is the mean number of WMS after treatment application

Table 2: Insecticide and pruning treatment combinations

Insecticides	Pruning type	Treatment combination
	Pruned (P_0)	
Thiamethoxam 25% WG soil drenching (I_0)	Pruned (P_0)	I_0 P_0
Dimethoate 40% EC (I_1)	Pruned (P_0)	I_1 P_0
Confidence 35% SC (I_2)	Pruned (P_0)	I_2 P_0
Movento 150 OD (I_3)	Pruned (P_0)	I_3 P_0
Thunder 145 OD (I_4)	Pruned (P_0)	I_4 P_0
Kuto (I_5)	Pruned (P_0)	I_5 P_0
Toran 240 (I_6)	Pruned (P_0)	I_6 P_0
Perfecto 17.5% SC (I_7)	Pruned (P_0)	I_7 P_0
Control (un-treated) (I_8)	Pruned (P_0)	I_8 P_0
	Non pruned (P_1)	
Thiamethoxam 25% WG soil drenching (I_0)	Non-pruning (P_1)	I_0 P_1
Dimethoate 40% EC (I_1)	Non-pruning (P_1)	I_1 P_1
Confidence 35% SC (I_2)	Non-pruning (P_1)	I_2 P_1
Movento 150 OD (I_3)	Non-pruning (P_1)	I_3 P_1
Thunder 145 OD (I_4)	Non-pruning (P_1)	I_4 P_1
Kuto (I_5)	Non-pruning (P_1)	I_5 P_1
Toran 240 (I_6)	Non-pruning (P_1)	I_6 P_1
Perfecto 17.5% SC (I_7)	Non-pruning (P_1)	I_7 P_1
Control (non-treated) (I_8)	Non-pruning (P_1)	I_8P_1

3.3.2. Evaluation of different oils, detergents and tree pruning

Mineral oil, ordinary vegetable oil, white oil and pruning were used alone and in combination with each other as treatments for evaluation of different oils, detergent and pruning practice. White oil was the mixture of oil (25ml) and liquid soap (6.5ml) in 15L of water applied for three trees using knapsack sprayer. Mineral oil and ordinary vegetable oil also used 150ml per 15L water for three trees using knapsack sprayer. Pruning was done using a hand held saw to remove old and dead branches and twigs to open the canopy and in order to allow entry of adequate sunlight to the lower canopy of the mango trees. Control (untreated) was sprayed with equal amount of water (15L) for three trees to compensate water effect.

Treatments were applied twice, at flowering stage in January and near harvesting time in April when the white mango scale population was expected to be high or at its peak. Mineral oil, Ordinary vegetable oil, White oil and Pruning were used alone and in combination with each other. In total 11 treatments including untreated (control) (Table 3). The treatments were arranged in a randomized complete block designs and replicated three times. One mango tree was used as one plot and a total of 33 mango trees were used for the application of the treatments.

Twelve leaves were randomly picked from the lower branch of each tree in four cardinal directions prior to treatment application to count and estimate the level of infestation by the white mango scale. The leaves were kept in plastic bags and transported to AARC entomology laboratory for counting. The Number of crawler, male and females of white mango scale were counted using a stereoscopic microscope. The adult female has circular armor, flat, thin and often wrinkled. Male armors are small, white, sides nearly parallel. Crawlers were deep bright brick red. Mean number of insects from post treatments application were used to assess the efficacy of the treatments.

The number of white mango scale per 12 randomly selected leaves was counted in each replicate and mean numbers obtained after each application. The percent of white mango scale reduction was calculated by:

$$\text{Percent of reduction} = \frac{\text{Original No.} - \text{New No.}}{\text{Original number}} \text{ X}100$$

Where Original No. is the mean number of WMS before treatment application and

New No. is the mean number of WMS after treatment application

Table 3: Mineral oils, detergent and pruning practices combinations

Treatments number	Treatments name
1	Mineral oil
2	Mineral oil plus Ordinary vegetable oil
3	Mineral oil plus White oil
4	Mineral oil plus Pruning
5	Ordinary vegetable oil
6	Ordinary vegetable oil plus White oil
7	Ordinary vegetable oil plus Pruning
8	White oil
9	White oil plus Pruning
10	Pruning
11	Control (untreated)

3.4. Statistical Analysis

All data were checked for normality and/or homogeneity of variance using Shapiro-Wilk test. Count data were transformed using Log_{10} transformation and Arcsine transformation was used for percent of reduction of WMS. The data were subjected to analysis of variance (ANOVA) using the SAS software version 9 and ANOVA was followed by mean separation using the LSD test at 95% confidence level.

4. RESULTS AND DISCUSSION

4.1. Efficacy of Different Insecticides and Pruning after First Round Application

Mean number of WMS (male, female and crawlers) per twelve leaves prior to the first treatment application ranged between 38.2 and 43.2. However, the mean number of WMS varied from 1.6 to 50.05 after first treatment application of different insecticides and pruning while 64.7 on the untreated trees (Figure 2). The higher mean number of WMS was recorded from untreated trees (64.7) and Perfecto 17.5% SC treated trees (50.05). The mean number of WMS for untreated was increased from 43.2 (pre-treatment) to 64.7 (first treatment application). The analysis of variance revealed that the main effect which is insecticides and pruning had significant ($P < 0.05$) effect on the mean numbers of WMS after first application (Figure 2 and 3, Appendix 1). However, the interaction of both insecticides and pruning did not influence the mean numbers of WMS (Appendix 1).

Among the insecticides, Movento 150 OD significantly decreased the mean number of WMS (1.57) compared to others insecticides and untreated control (Figure 2). Dimethoate 40% EC (11.8) and Toran 240 (15.2) also significantly decreased the number of WMS compared to untreated, Confidence 35% SC and Perfecto 17.5% SC. While, there were no a significance difference between the treatment of Dimethoate 40% EC, Toran 240, Thiamethoxam 25% WG, Thunder 145 and Kuto. Confidence 35% SC, Perfecto 17.5% SC and untreated also the list effective in terms of suppressing WMS population and there was no significant difference. However, Confidence 35% SC was statistically similar with the treatment of Thiamethoxam 25% WG, Thunder 145 and Kuto after first spray of insecticides. This result was consistent with Ayalew *et al*., (2015), who reported that foliar application of Movento 150 OD significantly decreased the presence of white mango scale after first spray. Smiley *et al*., (2011), also reported that foliar application of Movento 150 OD can reduce fecundity of sucking insects which feed on wheat root and foliage.

Pruning had significantly decreased the mean number of white mango scale (23.83) compared to non-pruned (31.97) trees during the first treatment application (Figure 3). This could be duet the fact that tree pruning eliminate infested twigs and branches thereby reduced tree infestation by

WMS. Previous studies by Bautista-Rosales *et al*., (2013) and Djirata *et al*., (2016) reported that mango tree pruning significantly decreased WMS.

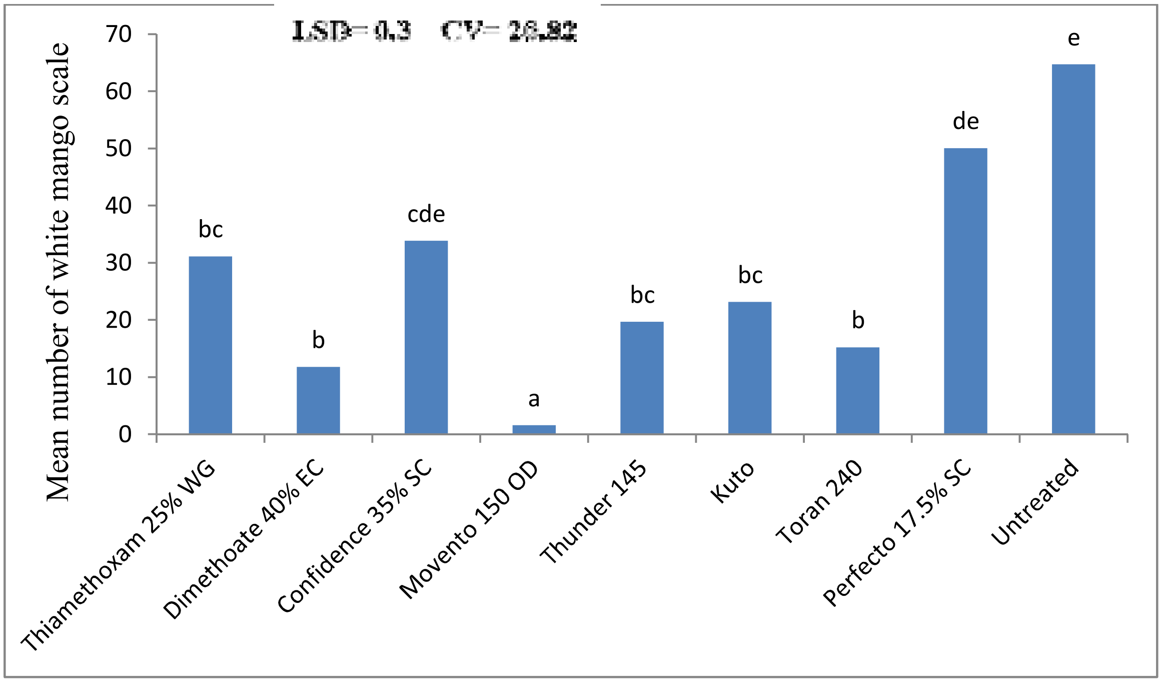

Figure 2: Efficacy of different insecticides on mean numbers of white mango scale after first treatment application**.** Means with the same letter(s) are not significantly different at P = 0.05.

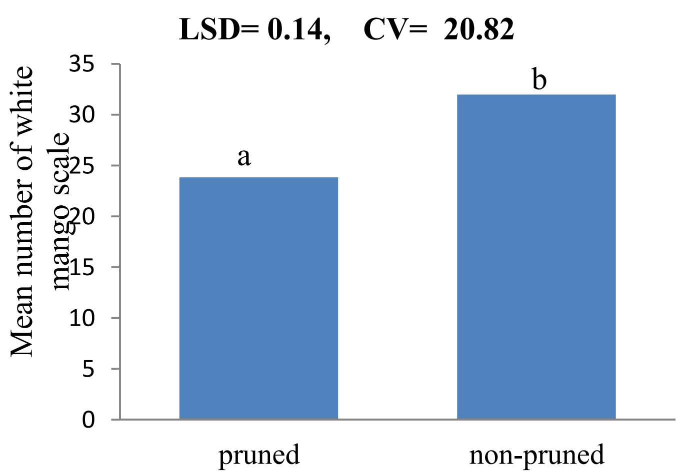

Figure 3: The effect of pruning on mean number of white mango scale after first treatment application**.** Means with the same letter(s) are not significantly different at P = 0.05.

4.2. Efficacy of Different Insecticides and Pruning after Second Round Application

Different insecticides and pruning had significant ($P < 0.05$) effect on the mean numbers of white mango scale after the second treatment application (Figures 4 and 5). The mean number of WMS recorded from twelve leaves in Dimethoate 40% EC treated tree was 2.3 after second application. This was observed during the month of May when the infestation of white mango scale was very high. Dimethoate 40% EC significantly decreased the mean number of white mango scale compared to other insecticides (Figure 4). The mean number of white mango scale in Thunder 145 OD (10.9), Toran 240 (11.1), Movento 150 OD (11.1), Kuto (1.2) and Thiamethoxam 25% WG (13.4) was significantly lower compared to untreated (58.6) and Confidence 35% SC (30.6) after second application of insecticides.

Mani and Krishnamurthy, (2001) reported that at the early stages, scales were effectively controlled with the sprays of Dimethoate. Salahuddin *et al.,* (2015) also confirmed that application of Thiamethoxam at the point of drip irrigation was most effective for the control of scale insects and mealy bugs on mangos in South Africa. Al-kazafy *et al.*, (2015) also reported that use of Thiamethoxam 25% WG treated seeds can be an important alternative for management on cotton.

On the other hand pruning also significantly decreased the mean number of white mango scale (14.7) compared to non-pruned (24) after second treatment (Figure 5).

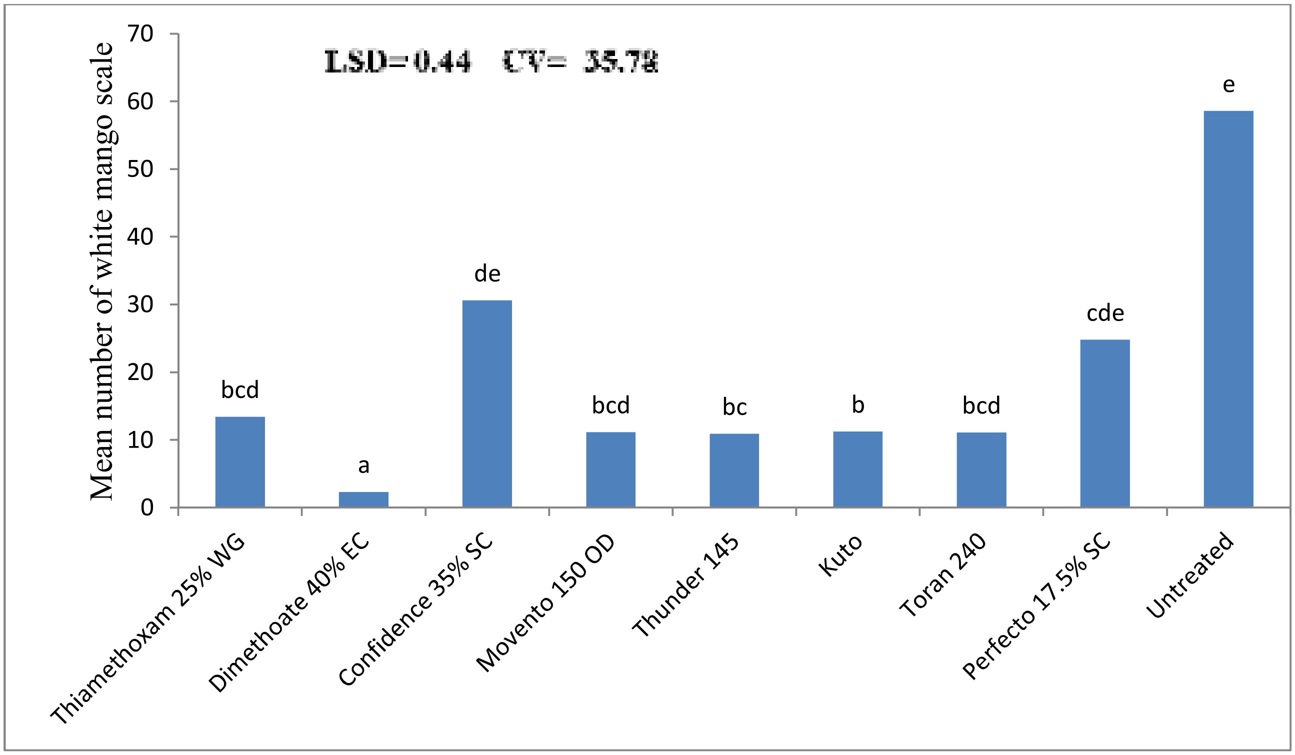

Figure 4: Efficacy of different insecticides on mean number of white mango scale after second treatment application**.** Means with the same letter(s) are not significantly different at P = 0.05.

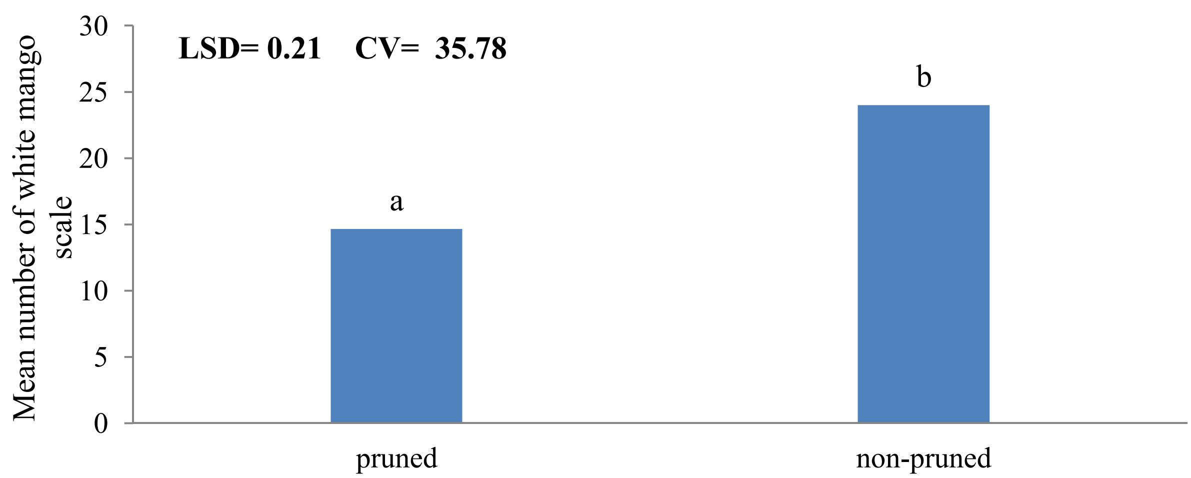

Figure 5: The effect of pruning on mean number of white mango scale after second treatment applications**.** Means with the same letter(s) are not significantly different at P = 0.05.

4.3. Percent Reduction of White Mango Scale after First Application of Insecticides and Pruning

Percent reduction of different insecticides showed a significant difference after first application. However, pruning as well as the interaction of both factors had not significant percent reduction after first application of treatments. In most treatments percent of reduction showed positive number from 18.34% to 96.23% after first spray of different insecticides. Movento 150 OD (96.23%) was found to be effective in showing high percent reduction over untreated (control) and treated plots (Table 4). Dimethoate 40% EC and Toran 240 were also superior over control, Perfecto 17.5% SC, Confidence 35% SC and Thiamethoxam 25% WG with 70.3 and 62.21 percent reduction respectively. However, untreated (control) plots as well as Perfecto 17.5% SC, Confidence 35% SC and Thiamethoxam 25% WG treated plots though were, the least effective among the treatments.

4.4. Percent Reduction of White Mango Scale after Second Application of Insecticides and Pruning

Percent reduction of white mango scale after second application of insecticides and pruning showed significant difference among the main effects of insecticides and pruning. However, the interaction of both effects did not influence the percent reduction of white mango scale after second application of the treatment. Dimethoate 40% EC, Thiamethoxam 25WG, Thunder 145 OD and Movento 150 OD was found to be effective in recording high percent reduction over control after second application of insecticide compared to Confidence 35% SC and Perfecto 17.5% SC. Untreated (-39.35%) though superior over control was the least effective among the other treatments (Table 4). Pruning also affected the percent reduction of white mango scale and pruned treatments were superior over control with 63.63% percent reduction over control compared to non-pruned (41.68%), (Table 5).

Table 4: Initial count and percent reduction of white mango scale after first and second spray

Different insecticides	Mean number of WMS Pre-spray	Mean number of WMS after first spray	Percent reduction of WMS after first spray	Mean number of WMS after second spray	Percent reduction of WMS after second spray
Thiamethoxam 25% WG	41.98(1.62)	31.13(1.46)	25.84(4.35)	13.4(1)	68.08(8.03)
Dimethoate 40% EC	39.67(1.6)	11.78(1.03)	70.3(8.35)	2.32(0.28)	94.16(9.7)
Confidence 35% SC	41.45(1.62)	33.85(1.5)	18.34(4.29)	30.62(1.39)	26.14(4.07)
Movento 150 OD	41.58(1.62)	1.57(0.052)	96.23(9.81)	11.13(1.02)	73.23(8.56)
Thunder 145	40.68(1.61)	19.67(1.25)	51.65(6.94)	10.9(0.91)	73.21(8.49)
Kuto	39.8(1.6)	23.15(1.26)	41.83(6.2)	11.23(0.79)	71.78(8.34)
Toran 240	40.27(1.6)	15.22(1.05)	62.21(7.27)	11.07(0.97)	72.52(8.47)
Perfecto 17.5% SC	39.28(1.59)	50.05(1.65)	-27.42(1.5)	24.8(1.31)	36.86(4.80)
Untreated	42.03(1.62)	64.7(1.77)	-53.94(0.58)	58.57(1.72)	-39.35(1.82)
$LSD_{(0.05)}$	004^{ns}	0.3*	2.83*	0.44*	2.73*
CV (%)	1.97	20.82	44.1	35.78	33.6
SEM±	0.001	0.06	5.83	0.14	5.41

Values in the bracket represented transformed data using Log_{10} for count data and Arcsine for percent of reduction. Mean separation obtained from transformed data.

Table 5: Initial count and percent reduction of white mango scale after first and second pruning treatment

Pruning level	Mean number of WMS Pre-treatment	Mean number of WMS after first treatment	Percent reduction of WMS after first treatment	Mean number of WMS after second treatment	Percent reduction of WMS after second treatment
Pruned	40.31(1.61)	23.83(1.13)	40.88(6.11)	14.66(0.93)	63.63(7.62)
Non pruned	41.19(1.6)	31.97(1.32)	22.38(4.84)	24.02(1.15)	41.68(6.22)
$LSD_{(0.05)}$	0.02^{ns}	0.14*	1.34ns	0.21*	1.29*
CV (%)	1.96	20.82	44.1	35.78	33.6
SEM±	0.001	0.06	5.83	0.14	5.41

Values in the bracket represented transformed data using Log_{10} for count data and Arcsine for percent of reduction. Mean separation obtained from transformed data.

4.5. Efficacy of Oils, Detergents and Pruning after First Application

The ANOVA showed that there were no a significant difference among treatments before first application of different oils, detergents and pruning (Appendix 3). The mean number of white mango scale per leaf from 12 leaves before treatment application were recorded a minimum number of 38.93 and a maximum number of 52.03 in the treatments.

The mean number of white mango scale per leaf from 12 leaves after the first application of different treatments showed a significant ($P < 0.05$) effect on the number of white mango scale insects (Figure 6). The ANOVA showed mineral oil plus white oil significantly decreased the mean number of white mango scale compared to other treatments after first application. Mean number of white mango scale in the untreated (57) was triple fold than that of mineral oil plus white oil (15.97) and mineral oil plus ordinary vegetable oil (18.03) and twice higher than Ordinary vegetable oil plus White oil (27.5) after the first application.

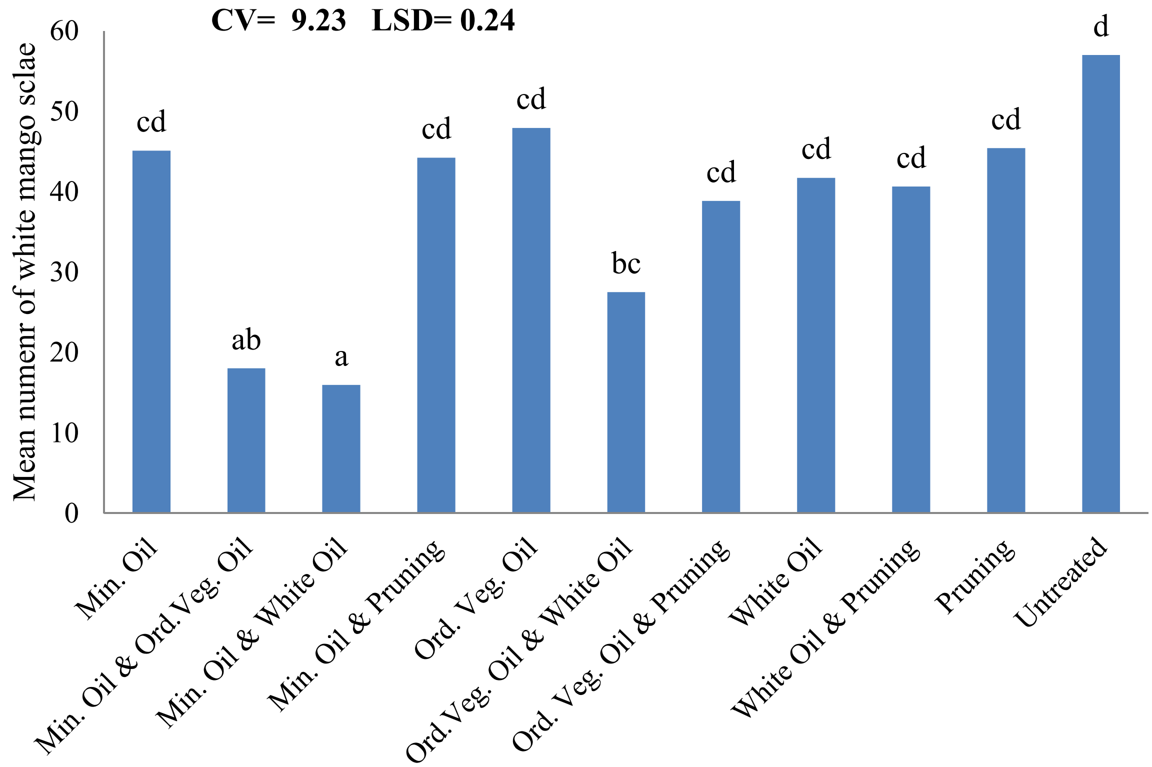

Figure 6: Mean no. of white mango scale after first application of different oils, detergent and pruning practices**.** Means with the same letter(s) are not significantly different at P = 0.05.

4.6. Efficacy of Oils, Detergents and Pruning after Second Application

After the second application of treatments the ANOVA showed had significant ($P < 0.05$) effects were observed on the mean numbers of white mango scale. Mineral oil plus white oil and ordinary vegetable oil plus white oil showed lower number of white mango scale after second application compared to other treatments. The ANOVA revealed that the mean number of white mango scale in the untreated (53.1) were 6, 6 and 4 times over that of mineral oil plus white oil (8.2), Ordinary vegetable oil plus White oil (8.37) and White oil plus pruning (13) respectively (Figure 7). White oil plus pruning and mineral oil plus ordinary vegetable oil also showed slightly higher number of white mango scale compared to ordinary vegetable oil plus white oil and significantly decreased the mean number of white mango scale than the rest treatments after second application of treatments.

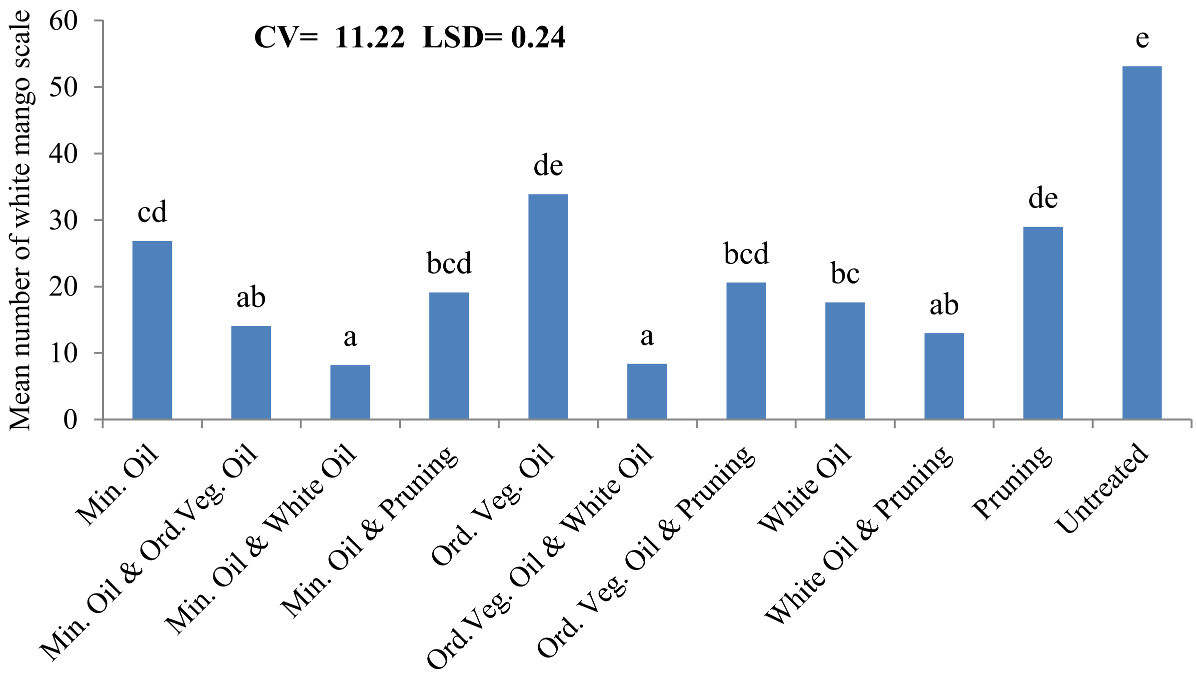

Figure 7: Mean no. of white mango scale after second application of different oils, detergent and pruning practices. Means with the same letter(s) are not significantly different at P = 0.05.

4.7. Percent Reduction of White Mango Scale after Application of Different Oils, Detergents and Pruning

Most of the treatment percent reduction showed positive number from 2% to 60% and from 24% to 83% after first and second application of treatments respectively (Table 6). The result indicates the number of white mango scale decreased after first and second application of treatments compared to the number of white mango scale before application of the treatments. Mineral oil plus ordinary vegetable oil (59.9%) and mineral oil plus white oil (59%) showed significant reduction of white mango scale after first spray and ordinary vegetable oil plus white oil (82.8%) and mineral oil plus white oil (78.9%) gave higher percent reduction in the number of white mango scale after second spray. Although the application of Ordinary vegetable oil showed negative percent reduction after first spray (-7.2) it means the number of white mango scale increased by 7.2% compared to before spray. Untreated trees also showed negative percent reduction after first and second application of the treatment (-24.8 and -16.1) respectively.

Table 6: Percent reduction of white mango scale on different oils, detergent and pruning practices

Different oils, detergent and pruning practices	Mean number of WMS Pre-treatment	Mean number of WMS after first treatment	Percent reduction of WMS after first treatment	Mean number of WMS after second treatment	Percent reduction of WMS after second treatment
Mineral oil	46.07(1.66)	45.1(1.64)	2.11(1.31)	26.87(1.42)	41.68(6.06)
Mineral oil and Vegetable oil	45(1.65)	18.03(1.23)	59.92(7.78)	14.07(1.13)	68.74(8.09)
Mineral oil and White oil	38.93(1.52)	15.97(1.16)	58.98(5.99)	8.2(0.9)	78.94(7.8)
Mineral oil and Pruning	46.33(1.62)	44.23(1.64)	4.53(1.99)	19.13(1.28)	58.7(5.5)
Vegetable oil	44.7(1.59)	47.93(1.65)	-7.23(1.85)	33.9(1.52)	24.16(4.09)
Vegetable oil and White oil	48.77(1.68)	27.5(1.44)	43.61(6.25)	8.37(0.89)	82.84(9.1)
Vegetable oil and Pruning	44.83(1.63)	38.83(1.58)	13.38(3.52)	20.6(1.3)	54.05(7.31)
White oil	46.23(1.64)	41.73(1.61)	9.73(2.87)	17.63(1.24)	61.86(7.63)
White oil and Pruning	43.53(1.61)	40.63(1.6)	6.65(2.53)	13(1.07)	70.14(7.64)
Pruning	52.03(1.72)	45.4(1.64)	12.74(3.36)	29(1.43)	44.26(6.47)
Untreated	45.77(1.64)	57(1.75)	-24.54(0)	53.13(1.7)	-16.09(3.13)
LSD $(_{0.05})$	0.33ns	0.24	3.04*	0.24*	3.76*
CV (%)	11.8	9.23	52.4	11.22	33.34
SEM±	0.037	0.02	3.19	0.02	4.87

Values in the bracket represented transformed data using Log_{10} for count data and Arcsine for percent of reduction. Mean separation obtained from transformed data.

5. CONCLUSION AND RECOMMENDATIONS

Recently production and productivity of mango is constrained by various pests including the invasive white mango scale insect pest. Since 2010, white mango scale is a new insect pest and a major problem of mango production in Western Oromia East Wollega Zone Guto Gida district. The interaction effect of different insecticides and pruning did not show significant difference in terms of white mango scale suppression during the first and second application under field conditions. However, significant difference was observed in the main effects (insecticides and pruning), after first application. Among the insecticides, Movento 150 OD (60ml/15L/3 trees) was found effective in management of WMS scale after first and second application. Dimethoate 40% EC (50ml/15L/3 trees) was also slightly effective after first application and highly effective after second application in terms of suppression of WMS. The lowest mean number of WMS (1.57) was recorded in Movento 150 OD treated plots followed by Dimethoate 40% EC (11.8) after first application and Dimethoate 40% EC (2.3) after second application.

Mineral oil plus white oil gave lower number of WMS after first and second application (15.97 and 8.2), respectively. Similarly, high percent reduction of WMS (59.9%) was recorded from plot treated with mineral oil plus ordinary vegetable after first application. After second application of different oils, detergent and pruning high percent reduction of WMS were obtained from plots treated with white oil plus ordinary vegetable oil (82.8%) and mineral oil plus ordinary vegetable oil (68.74%). Generally, white mango scale responded well to the application of different insecticides with and without pruning in terms of suppressing the population of white mango scale and application of different oils, detergents and pruning used alone as well as in combination. From the finding of the current study suggested that combined application of mineral oil (150 ml/15 L/3 trees) plus white oil (mixture of 25 ml Oil and 6.5 ml liquid soap in 15 L water for three mango trees) and/or pruning efficiently reduce WMS and could be practiced by mango producers particularly smallholders.. In addition to this, private companies and investors as well as trained mango growers also advised to use Dimethoate 40% EC (50 ml/15 L/3 trees) and Movento 150 OD (60 ml/15 L/3 trees) at pick infestation period. Future work should also focus on training the full packages of the use of chemical insecticides such as, chemical formulation, dosage, equipment's for spray. Further studies should investigate effect of time on pest management application, insect habitat, insect behavior and also effectiveness of various integrated WMS management by considering the different developmental stages of the WMS.

Moreover, future pest management program should investigate the effect of season and location on the control efficacy of various component of IPM include insecticides, mineral oils and white oil and also their effect on associated natural enemies for sustainable management of white mango scale insect pests.

REFERENCES

Abhilash, P.C. and Singh, N., 2009. Pesticide use and application: an Indian scenario. *Journal of hazardous materials*, *165*(1-3), pp.1-12.

Abo-Shanab, A.S.H., 2012. Suppression of white mango scale, Aulacaspis tubercularis (Hemiptera: Diaspididae) on mango trees in El-Beheira Governorate, Egypt. *Egypt. Acad. J. Biolog. Sci*, *5*(3), pp.43-50.

Alemayehu Chala, Muluken Getahun, Samuel Alemayehu and Mekuria Tadesse (2014). Survey of mango anthracnose in southern Ethiopia and in-vitro screening of some essential oils against Colletotrichum gloeosporioides.

International Journal of Fruit Science 14:157-173.

Al-Kazafy, H., Abd-El Rahman, T.A. and Abolmaaty, S.M., 2015. Influence of some new insecticides on sweetpotato whitefly, Bemisia tabaci and American serpentine leafminer, Liriomyza trifolii and their residues in cucumber fruits. *International Journal*, *3*(10), pp.1874-1881.

Ayalew, G., Fekadu, A. and Sisay, B., 2015. Appearance and Chemical Control of white mango scale (Aulacaspis tubercularis) in Central Rift Valley. *Science, Technology and Arts Research Journal*, *4*(2), pp.59-63.

Banerjee, G.D. and Banerjee, G.D., 2011. *Economics of mango cultivation*. National Bank for Agricultur and Rural Development.

Bautista-Rosales,P.U., Ragazzo-Sánchez,J.A., Calderón-Santoyo, M., CortézMondaca, E. and Servín-Villegas,R.(2013). Aulacaspis tubercularis Newstead in mango orchards of Nayarit, Mexico, and relationship with environmental and agronomic factors. Southwestern Entomologist 38(2):221-230.

Beck, S.D., 1965. Resistance of plants to insects. *Annual review of entomology*, *10*(1), pp.207-232.

Camacho, E.R. and Chong, J.H., 2015. General biology and current management approaches of soft scale pests (Hemiptera: Coccidae). *Journal of integrated pest management*, *6*(1), p.17.

Cowles, R.S., 2014. Systemic insecticide impacts on the environment and bee pollinators.

CSA, (2017): Agricultural Sample Survey 2016 / 2017; Volume I, Report on Area and Production of Major Crops, Statistical Bulletin 584; Addis Ababa, Ethiopia

Daneel, M.S. and Dreyer, S., 1997. Further studies on the establishment of Aphytis sp. and Cybocephalus binotatus in mango orchards for the control of mango scale. *South African Mango Growers' Association Yearbook*, *17*, pp.144-146.

Daneel, M.S. and Dreyer, S., 1998. Biological control of the mango scale, Aulacaspis tubercularis, in South Africa. *Yearbook-South African Mango Growers' Association*, *18*, pp.52-55.

Daneel, M.S. and Joubert, P.H., 2006, February. Biological control of the mango scale Aulacaspis tubercularis Newstead (Coccidae: Diaspididae) by a parasitoid Aphytis chionaspis Ren (Hymenoptera: Aphelinidae). In *VIII International Mango Symposium 820* (pp. 567-574).

DeLoach, C.J., 1974. Rate of increase of populations of cabbage, green peach, and turnip aphids at constant temperatures. *Annals of the Entomological Society of America*, *67*(3), pp.332-340.

Djirata, O., Getu, E. and Kahuthia-Gathu, R., 2016. Trend in Mango Production and Potential Threat from Emerging White Mango Scale, Aulacaspis tubercularis (Homoptera: Diaspididae) in Central and Eastern Kenya. *Journal of Natural Sciences Research.(6)*, *7*, pp.87-94.

Dinka, T.D., Terefe, T.H., Wendafrash, B.H. and Edosa, T.T., Distribution and Population Dynamics of the White Mango Scale, Aulacaspis tubercularis in Southwest Ethiopia.

Dharmendra, S., Rajendra, S., Jitendra, S., & Hariom, K. (2013). Influence of weather parameters on population fluctuation of scale insect, Aulacaspic tubercularis (Newstead) in mango. *Annals of Horticulture*, *6*(2), 267-271.

Dreistadt, S.H., 2007. *Integrated pest management for avocados* (Vol. 3503). UCANR Publications.

Duressa TF, 2018. Newly Emerging Insect Pests and Diseases as a Challenge for Growth and Development of Ethiopia: The Case of Western Oromiya

Eagling, D., 2009. Soilborne diseases in the context of plant biosecurity. *Australasian Plant Pathology*, *38*(4), pp.334-337.

EIAR, 2018. National tropical fruits research program. Designed by EIAR ICT directoret, link http://www.eiar.gov.et/marc/index.php/anrl-research/crop-research

Evans, P.D., Kerkut, G.A. and Gilbert, L., 1985. Comprehensive insect biochemistry, physiology and pharmacology. *by GA Kerkut & L. Gilbert, Pergamon Press, Oxford*, pp.499-503.

FAO, Publishing & Multimedia service, FAO, Rome, 2002.

FAO, 2009: Utilization of tropical foods: fruit and leaves. Food and nutrition paper, via delle terme dicaracalla, 00100 Rome, Italy.

FiBL, Research Institute of Organic Agriculture, Switzerland,**www.fbl.org**. African Organic Agriculture Training Manual A Resource Manual for Trainers Draft Version 1.0 June 2011

Fita, T., 2014. White mango scale, Aulacaspis tubercularis, distribution and severity status in East and West Wollega Zones, western Ethiopia. *Science, Technology and Arts Research Journal*, *3*(3), pp.1-10.

Food and Agriculture Organization of the United Nation (FAO). (2010). Technical guidelines on tropical fruit tree management in Ethiopia, FAO.

Frank, S.D., 2012. Reduced risk insecticides to control scale insects and protect natural enemies in the production and maintenance of urban landscape plants. *Environmental entomology*, *41*(2), pp.377-386.

Germain, J.F., Vayssieres, J.F. and Matile-Ferrero, D., 2010. Preliminary inventory of scale insects on mango trees in Benin. *Entomologia Hellenica*, *19*(2), pp.124-131.

Government of India Ministry of Agriculture, 2012. Major uses of pesticides Registered under the Insecticides Act, 1968

Griesbach, J., 2003. *Mango growing in Kenya*. World Agroforestry Centre.

Halteren, P.V., 1970. Notes on the biology of the scale insect Aulacaspis mangiferae Newst.(Diaspididae, Hemiptera) on mango. *Ghana Journal of Agricultural Science*, *3*(2), pp.83-85.

Hodges, G. and Hamon, A., 2006. Pest Alert. White mango scale Aulacaspis tubercularis Newstead (Coccoidea: Diaspididae). Florida Department of Agriculture and Costumer Services. Division of Plant Industry.

Hodges, G. and Hamon, A., 2016. White Mango Scale, Aulacaspis tubercularis Newstead (Coccoidea: Diaspididae). *Pest Alert, Florida Department of Agriculture and Consumer Services, Pest Alert Division of Plant Industry, Pest Alert*.

Hoegh-Guldberg, O., Hughes, L., McIntyre, S., Lindenmayer, D.B., Parmesan, C., Possingham, H.P. and Thomas, C.D., 2008. Assisted colonization and rapid climate change.

Honja, T., 2014. Review of mango value chain in Ethiopia. *J Biol Agric Healthc*, *4*(25), pp.230-239.

Howard, F.W., 1989. insecticidal control of magnolia white scale and long-tailed mealybug on sago-palms1. In *Proc. Fla. Turfgrass Mgt. Conf* (Vol. 27, pp. 61-65).

Inayatullah, C., Webster, J.A. and Fargo, W.S., 1990. Index for measuring plant resistance to insects. *Entomologist*, *109*(3), pp.146-152.

Johnson, R., and M. L. Corn. 2015. Bee health: The role of pesticides. United States Congress, Lybrary of Congress, Congressional Research Service Report 7-5700, R43900 (http://fas.org/sgp/crs/misc/R43900.pdf). Last accessed 18 August 2015.

Joosten, F.J., 2007. *Development strategy for the export-oriented horticulture in Ethiopia*. Wageningen Ur.

Joubert, P.H., Daneel, M.S. and Grove, T., 1999, April. Progress towards integrated pest management (IPM) on mangoes in South Africa. In *VI International Symposium on Mango 509* (pp. 811-818).

Juárez-Hernández, P., Valdez-Carrasco, J., Valdovinos-Ponce, G., Mora-Aguilera, J.A., Otero-Colina, G., Téliz-Ortiz, D., Hernández-Castro, E., Ramírez-Ramírez, I. and González-Hernández, V.A., 2014. Leaf penetration pattern of Aulacaspis tubercularis (Hemiptera: Diaspididae) stylet in mango. *Florida Entomologist*, *97*(1), pp.100-107.

Kabashima, J. N., and S. H. Dreistadt. 2014. Scales: integrated pest management for home gardeners and landscape professionals. University of California, Agriculture and Natural Resources, Statewide Integrated Management Program, Pest Notes, Publication 7408, Davis, CA.

Karar, H., Arif, M.J., Ali, A., Hameed, A., Abbas, G. and Abbas, Q., 2012. Assessment of yield losses and impact of morphological markers of various mango (Mangiferae indica) genotypes on mango mealybug (Drosicha mangiferae Green)(Homoptera: Margarodidae). *Pakistan Journal of Zoology*, *44*(6).

Kayode, R.M.O. and Sani, A., 2008. Physicochemical and proximate composition of mango (Mangifera indica) kernel cake fermented with mono-culture of fungal isolates obtained from naturally decomposed mango kernel. *Life Science Journal*, *5*(4), pp.55-63.

Kogan, M. and Ortman, E.F., 1978. Antixenosis–a new term proposed to define Painter's "nonpreference" modality of resistance. *Bulletin of the ESA*, *24*(2), pp.175-176.

Kondo, T. and Muñoz-Velasco, J.A., 2009. Nuevos registros de Aulacaspis tubercularis Newstead (Hemiptera: Diaspididae) en Colombia y experimentos de transferencia de hospederos. *Rev. Asiava*, *84*, pp.18-20.

Kumari, D.A., Anitha, V. and Lakshmi, B.K.M., 2014. Evaluation of insecticides for the management of scale insect in mango (Mangifera indica). *International Journal of Plant Protection*, *7*(1), pp.64-66.

Louw, E.C., Labuschagne and Swart, SH.(2008). *Developing a mango programme for optimum mango yield and quality. SA Mango growers' association Research Journal*, *28*, pp.1-11.

Labuschagne, T.I. and Pasques, B.P., 1994. Imported parasites of the mango scale, Aulacaspis tubercularis, and the effect of fenthion on the mango parasitoid, Aspidiotiphagus citrinus. *Yearbook-South African Mango Growers' Association*, *14*, pp.75-77.

Labuschagne, T.I., Daneel, M.S. and De Beer, M., 1996. Establishment of Aphytis sp.(Hymenoptera: Aphelinidae) and Cybocephalus binotatus Grouvelle (Coleoptera: Nitidulidae) in mango orchards in South Africa for control of the mango scale, Aulacaspis tubercularis Newstead (Homoptera: Diaspididae). *South African Mango Growers' Association Yearbook (South Africa)*.

Ma, X., Wu, H., Liu, L., Yao, Q., Wang, S., Zhan, R., Xing, S. and Zhou, Y., 2011. Polyphenolic compounds and antioxidant properties in mango fruits. *Scientia Horticulturae*, *129*(1), pp.102-107.

Malumphy, C., 2014. An annotated checklist of scale insects (Hemiptera: Coccoidea) of Saint Lucia, Lesser Antilles. *Zootaxa*, *3846*(1), pp.069-086.

Mani, M. and Krishnamoorthy, A., 2001. Suppression of Maconellicoccus hirsutus (Green) on guava. *Insect Environment*, *6*(4).

Manners, A, 2016. Building the resilience and on-farm biosecurity capacity of the Australian production nursery industry.

McClure, M.S., 1985. Susceptibility of pure and hybrid stands of Pinus to attack by Matsucoccus matsumurae in Japan (Homoptera: Coccoidea: Margarodidae). *Environmental entomology*, *14*(4), pp.535-538.

Miller, D.R., Miller, G.L., Hodges, G.S. and Davidson, J.A., 2005. Introduced scale insects (Hemiptera: Coccoidea) of the United States and their impact on US agriculture. *Proceedings of the entomological Society of Washington*, *107*(1), pp.123-158.

Miller, D.R. and Davidson, J.A., 2005. *Armored scale insect pests of trees and shrubs (Hemiptera: Diaspididae)*. Cornell University Press.

Mills, N. and Daane, K., 2005. Biological and cultural controls… Nonpesticide alternatives can suppress crop pests. *California agriculture*, *59*(1), pp.23-28.

Mohammed, D., Belay, H., Lemma, A., Konjit, F., Seyoum, H. and Teshome, B., 2012. White mango scale: A new insect pest of mango in Western Ethiopia. In *Proc. of 3rd Biennial Conference of Ethiopian Horticulture Science Society* (pp. 257-267).

Mukherjee, S.K. and Litz, R.E., 1997. The Mango: botany, production and uses. *The Mango: botany, production and uses*.

Nabil, H.A., Shahein, A.A., Hammad, K.A.A. and Hassan, A.S., 2012. Ecological studies of Aulacaspis tubercularis (Diaspididae: Hemiptera) and its natural enemies infesting mango trees in Sharkia Governorate, Egypt. *Acad. J. Biolog. Sci*, *5*(3), pp.9-17.

Netherer, S. and Schopf, A., 2010. Potential effects of climate change on insect herbivores in European forests—general aspects and the pine processionary moth as specific example. *Forest Ecology and Management*, *259*(4), pp.831-838.

New Zealand Biosecurity, 2018. PaDIL Species Factsheet Live link: http://www.padil.gov.au:80/maf-border/Pest/Main/141387

Nufarm Australia Limited ACN 004 377 780 103-105 Pipe Road Laverton North Victoria 3026, 2014. For the control of a wide range of insect pests on fruit, vegetables, oilseeds, cotton, cereals, pasture, turf and other situations

Nwinuka, N.M., Monanu, M.O. and Nwiloh, B.I., 2008. Effects of aqueous extract of Mangifera indica L.(Mango) stem bark on haematological parameters of normal albino rats. *Pakistan Journal of Nutrition*, *7*(5), pp.663-666.

Ofgaa, D.J. and Emana, D.G., 2015. Infestation of Aulacaspis tubercularis (Homoptera: Diaspididae) on mango fruits at different stages of fruit development, in western Ethiopia. *Journal of Biology, Agriculture and Healthcare*, *5*, pp.34-38.

Painter R. H., 1951. *Insect resistance in crop plants*. The Macmillan Company New York.

Parakash and Patil, 2018. Field evaluation of new insecticides against, scale insect, *Hemilecanium imbricans* (Coccidae: Homoptera) on mango.

Pellizzari, G. and Germain, J.F., 2010. Scales (Hemiptera, Superfamily Coccoidea). Chapter 9.3. *Alien terrestrial arthropods of Europe. BioRisk*, *4*(1), pp.475-510.

Pisa, L.W., Amaral-Rogers, V., Belzunces, L.P., Bonmatin, J.M., Downs, C.A., Goulson, D., Kreutzweiser, D.P., Krupke, C., Liess, M., McField, M. and Morrissey, C.A., 2015. Effects of neonicotinoids and fipronil on non-target invertebrates. *Environmental Science and Pollution Research*, *22*(1), pp.68-102.

Raupp, M.J., Webb, R.E., Szczepaniec, A., Booth, D. and Ahern, R., 2004. Incidence, abundance, and severity of mites on hemlocks following applications of imidacloprid. *Journal of Arboriculture*, *30*(2), pp.108-113.

Robinson, R.A., 1976. Plant pathosystems. In *Plant Pathosystems* (pp. 15-31). Springer, Berlin, Heidelberg.

Rossetto, C.J., Bortoletto, N., Walder, J.M.M., Mastrângelo, T.D.A., Carvalho, C.R.L., de Castro, J.V., Pinto, A.D.Q. and Cortelazzo, A.L., 2006. Mango resistance to fruit flies. II-resistance of the alfa cultivar.

Salahuddin, B., ur Rahman, H., Khan, I. and Daud, M.K., 2015. Incidence and management of coconut scale, Aspidiotus destructor Signoret (Hemiptera: Diaspididae), and its parasitoids on mango (Mangifera sp.). *Crop Protection*, *74*, pp.103-109.

Sarwar, M., Hamed, M., Rasool, B., Yousaf, M. and Hussain, M., 2013. Host preference and performance of fruit flies Bactrocera zonata (Saunders) and Bactrocera cucurbitae (Coquillett)(Diptera: Tephritidae) for various fruits and vegetables. *International Journal of Scientific Research in Environmental Sciences*, *1*(8), p.188.

Sarwar, M., Hamed, M., Yousaf, M. and Hussain, M., 2014. Surveillance on population dynamics and fruits infestation of Tephritid fruit flies (Diptera: Tephritidae) in mango (Mangifera indica L.) orchards of Faisalabad, Pakistan. *International Journal of Scientific Research in Environmental Sciences*, *2*(4), p.113.

Sarwar, M., Ahmad, N., Rashid, A. and Shah, S.M.M., 2015. Valuation of gamma irradiation for proficient production of parasitoids (Hymenoptera: Chalcididae & Eucoilidae) in the management of the peach fruit-fly, Bactrocera zonata (Saunders). *International journal of pest management*, *61*(2), pp.126-134.

Sayed, A.M.M., 2012. Influence of certain bio-agents and climatic changes on the population density of the white mango scale insect, Aulacaspis tubercularis Newstead. *Egypt. J. Agric. Res*, *90*(2), pp.607-624.

Salem, H.A., Mahmoudand, Y.A. and Ebadah, I.M.A., 2015. Seasonal abundance, number of generations and associated injuries of the white mango scale, Aulacaspis tubercularis (Mangifera)(Newstead)(Homoptera: Diaspididae) attacking mango orchards. *RESEARCH JOURNAL OF PHARMACEUTICAL BIOLOGICAL AND CHEMICAL SCIENCES*, *6*(4), pp.1373-1379.

Shah, S.M.M., Ahmad, N., Sarwar, M. and Tofique, M., 2014. Rearing of Bactrocera zonata (Diptera: Tephritidae) for parasitoids production and managing techniques for fruit flies in mango orchards. *International Journal of Tropical Insect Science*, *34*(S1), pp.S108-S113.

Singh, D.P., 1986. Breeding for Diseases Resistance and Insect Pest.

Small Research Activity Report (SRA). (2006). Assessment of mango diseases, pest and production problems in Pakistan, Department of primary industries and fisheries, Queensland.

Smiley, R.W., Marshall, J.M. and Yan, G.P., 2011. Effect of foliarly applied spirotetramat on reproduction of Heterodera avenae on wheat roots. *Plant disease*, *95*(8), pp.983-989.

Smith, D., Beattie, G. and Broadley, R., 1997. Citrus pests and their natural enemies: integrated pest management in Australia.

Smith, C. Michael. *Plant resistance to arthropods: molecular and conventional approaches*. Springer Science & Business Media, 2005.

Soysouvanh, P. and Hong, K.J., 2016. Scale insects (Hemiptera: Coccoidea) on mango in Laos.

Stark, J.D. and Banks, J.E., 2003. Population-level effects of pesticides and other toxicants on arthropods. *Annual review of entomology*, *48*(1), pp.505-519.

Stocks, I. and Peña, J.E., 2013. Recent adventive scale insects (Hemiptera: Coccoidea) and whiteflies (Hemiptera: Aleyrodidae) in Florida and the Caribbean Region. *Potential*

Invasive Pests of Agricultural Crops. CAB International, Wallingford, United Kingdom, pp.342-362.

Szczepaniec, A., Creary, S.F., Laskowski, K.L., Nyrop, J.P. and Raupp, M.J., 2011. Neonicotinoid insecticide imidacloprid causes outbreaks of spider mites on elm trees in urban landscapes. *PLoS One*, *6*(5), p.e20018.

Szczepaniec, A., Raupp, M.J., Parker, R.D., Kerns, D. and Eubanks, M.D., 2013. Neonicotinoid insecticides alter induced defenses and increase susceptibility to spider mites in distantly related crop plants. *PloS one*, *8*(5), p.e62620.

Szczepaniec, A. and Raupp, M.J., 2013. Direct and indirect effects of imidacloprid on fecundity and abundance of Eurytetranychus buxi (Acari: Tetranychidae) on boxwoods. *Experimental and applied acarology*, *59*(3), pp.307-318.

Terefe, T.H., Tsegaye, S. and Wakuma, T., 2014. White Mango Scale Insect's Infestations and Its Implications in Guto Gida and Diga Distrcts of East Wellega Zone. *ABC Research Alert*, *2*(2).

Thomson, L.J., Macfadyen, S. and Hoffmann, A.A., 2010. Predicting the effects of climate change on natural enemies of agricultural pests. *Biological control*, *52*(3), pp.296-306.

UNCTAD, United Nations Conference on Trade and Development (2016). Mango: an INFOCOMM commodity profile, http://unctad.org/en/ Publications Library/ INFOCOMM_cp07_Mango/ (assessed 30January 2017).

Urías-López, M.A., Osuna-García, J.A., Vázquez-Valdivia, V. and Pérez-Barraza, M.H., 2010. Fluctuación poblacional y distribución de la escama blanca del mango (Aulacaspis tubercularis Newstead) en Nayarit, México. *Revista Chapingo. Serie horticultura*, *16*(2), pp.77-82.

Walthall, W.K. and Stark, J.D., 1997. A comparison of acute mortality and population growth rate as endpoints of toxicological effect. *Ecotoxicology and Environmental Safety*, *37*(1), pp.45-52.

Wauthoz, N., Balde, A., Balde, E.S., Van Damme, M. and Duez, P., 2007. Ethnopharmacology of Mangifera indica L. bark and pharmacological studies of its main C-glucosylxanthone, mangiferin. *International Journal of Biomedical and Pharmaceutical Sciences*, *1*(2), pp.112-119.

Weinberger, K.M. and Lumpkin, T.A., 2005. Horticulture for poverty alleviation-the unfunded revolution.

Wiersinga, R.C. and Jager, A.D. (2009). Business Opportunities in the Ethiopian Fruit and Vegetable Sector, Report 2008 075.LEI, Wageningen. 51pp.

APPENDICES

Table-1: Analysis of variance showing mean squares before application, after first application and after second application for efficacy of insecticides and pruning.

Source of variation	DF	NWMSPrA	NWMSPoFA	NWMSPoSA
REP	2	0.002	0.16	0.425
CHEM	8	0.001 ^{ns}	1.54*	0.997**
PRU	1	0.0013 ^{ns}	0.5 *	0.636*
CHEM*PRU	8	0.001 ^{ns}	0.46 ^{ns}	0.027 ^{ns}
ERROR	34	0.001	0.06	0.14
CV (%)		1.97	20.81	35.78

Where; DF = degrees of freedom, NWMSPrA = number of white mango scale pre-application, NWMSPoFA = *number of white mango scale post first application,* NWMSPoSA = *number of white mango scale post second application, REP = replication, CHEM = chemical insecticide, PRU=pruning* CHEM*PRU *interaction of chemical insecticide and pruning, CV = coefficient of variation, NS, * and ** implies non-significant, significant and highly significance differences at 5% level of probability, respectively.*

Table-2: Analysis variance showing mean squares for percent reduction of WMS after first and second application of different insecticides and pruning.

Source of variation	DF	PER_WMSPFA	PER_WMSPSA
REP	2	14.22	0.07
CHEM	8	56.47 *	42.87*
PRU	1	21.81 ^{ns}	26.32*
CHEM*PRU	8	6.3^{ns}	5^{ns}
ERROR	34	5.83	5.4
CV (%)		4.1	33.6

Where; DF = degrees of freedom, PER_WMSPFA = *number of white mango scale post first application,* PER_WMSPSA = *number of white mango scale post second application, REP = replication, CHEM = chemical insecticide, PRU=pruning* CHEM*PRU *interaction of chemical insecticide and pruning, CV = coefficient of variation NS and * implies non-significant and significant differences at 5% level of probability, respectively.*

Table-3: Analysis variance showing mean squares before application, after first application and after second application for efficacy of oils, detergent and pruning.

Source of variation	DF	NWMSPrA	NWMSPoFA	NWMSPoSA
REP	2	0.06	0.017	0.074
TRT	10	0.079^{ns}	0.15*	0.19*
ERROR	20	0.037	0.02	0.02
CV (%)		11.81	9.23	11.22

Where; DF = degrees of freedom, NWMSPrA = number of white mango scale pre application, NWMSPoFA = *number of white mango scale post first application,* NWMSPoSA = *number of white mango scale post second application, REP = replication, TRT = treatment, CV = coefficient of variation, NS and * implies non-significant and significant differences at 5% level of probability, respectively.*

Table-4: Analysis variance showing mean squares for percent reduction of WMS after first and second application of oils, detergent and pruning.

Source of variation	DF	PER_WMSPFA	PER_WMSPSA
REP	2	2	17.6
TRT	10	16.59*	9.73*
ERROR	20	3.19	4.87
CV (%)		52.49	33.6

Where; DF = degrees of freedom, PER_WMSPFA *= number of white mango scale post first application* PER_WMSPSA *= number of white mango scale post second application, REP = replication,* TRT= *treatment and CV = coefficient of variation, NS, * and ** implies non-significant, significant and highly significance differences at 5% level of probability, respectively.*



Mixing white oil Soil drenching Pruning



Motorized sprayer Leaf sample Leveling



Knapsack sprayer Count WMS by stereomicroscope Female WMS

Figure-1: Different pictures captured during the research process at field and laboratory