Management of Blue Gum Chalcid (*Leptocybe invasa* Fisher & La Salle (Hymenoptera: Eulophidae) infestation on different species of *Eucalyptus* trees in Kalu district, Eastern Amhara, Ethiopia

Tigabu Redae Alle[1,*], Adane Tesfaye Lema[2], Seid Muhie Dawud[3]

[1]Sirinka Research Center, Forestry Research Directorate, Woldia, Ethiopia,
[2]Bahir Dar University, College of Agriculture and Environmental Sciences, Bahir Dar, Ethiopia
[3]Department of Forestry, College of Agriculture, Wollo University, Dessie, Ethiopia

ABSTRACT

The recently introduced chalcid pest known as the Blue Gum Chalcid (BGC) (*L. invasa*) is currently one of the major insect pests of *Eucalyptus* tree species in Ethiopia. A research was conducted in Kalu district, South Wollo, Eastern Amhara, Ethiopia, the main objective of which was to evaluate the effectiveness of synthetic insecticides, hoeing and water showering options against BGC. Two parallel experiments were conducted in the nursery and in the field. *Eucalyptus camaldulensis, E. saligna, E. viminalis, E. citrodora* and *E. globulus* were considered in the nursery at Chorisa. One to three-year old *E. camaldulensis* plantations were considered at Tikuro plantation site. At the nursery, seven treatments and at the field 10 treatments were tested in a Randomized Complete Block Design (RCBD) with three replications from January to February 2019, where treatments were applied 3 times at 15-day intervals. Results from the 1-year old plantation revealed that application of Dimethoate 40%, Carbofuran 3G and Dimethoate 40% + hoeing followed by Carbofuran 3G + hoeing and Thiamethoxam 25WG were effective in checking the BGC insect pest infestation. In the 3-year old plantation, Carbofuran 3G significantly reduced the infestation followed by Dimethoate 40%. At the nursery, Dimethoate 40% and Carbofuran 3G reduced the infestation followed by Carbofuran 3G + Dimethoate 40% and thiamethoxam 25WG. Water showering and hoeing did not reduce BGC infestation in all cases at the field plantations. Treatments that received synthetic insecticides and hoeing had low infestation, the reason for which was the insecticide rather than the hoeing, because the hoeing alone didn't differ from the control. Application of Dimethoate 40% and Carbofuran 3G with hoeing and weeding activities were recommended to manage and limit BGC insect pest infestations.

Keywords: Blue gum chalcid, Hoeing, Water showering, Chemical Management, *Eucalyptus* spp.
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* Corresponding author: redtiges1980@gmail.com

INTRODUCTION

Eucalyptus is among the most widely planted forest trees in the world (Boland *et al.*, 1984). Ethiopia grows eucalyptus trees extensively in plantations and woodlots to provide wood resources for economic and social purposes. Eucalyptus species are preferred due to their fast growing characteristics as well as their adaptability to a wide range of environments (Chilima *et al.,* 2017). In Ethiopia, planting of exotic species started with the introduction of *Eucalyptus*, approximately 110 years ago (Hedberg *et al.*, 2009). Plantations of exotic *Eucalyptus* make up more than 30% of Ethiopia's plantations, providing fuel-wood and construction timber (Alemu Gezahegne *et al.*, 2003). In Ethiopia, there are about 55 introduced species, five to 10 of which were planted in different parts of the country and are becoming popular (Friis, 1995). Species such as *Eucalyptus camaldulensis* Dehnh, *E. saligna* sm.*, E. grandis* W. Hill, *E. citriodora* Hook, *E. globulus* Labill, *E. maculate* Hook*, E. paniculata* sm.*,* and *E. robusta* sm. were introduced and except the last three the others were widely planted (Demel Teketay, 2000; Alemu Gezahegne *et al.*, 2003; Berhan Gessesse *et al*., 2016). In addition, *E. regnans* F. Muell, and *E. tereticornis* sm., are also among the eucalyptus species planted widely in different parts Ethiopia (Friis, 1995).

The wood from eucalyptus plantations is commonly used for construction purposes, fuel, poles and posts and is an important resource for subsistence farmers. It also provides ecological benefit, soil conservation, construction purpose, office and house furniture (FAO, 2000; Berhan Gessesse *et al.*, 2016). However, recently a number of constraints are impacting the development and production of Eucalyptus trees and insect pests are among the major ones. Over time, the incidence and impact of insect pests has increased and it is now posing a major impediment to the continued expansion of this important commodity. Insect pests of eucalyptus trees are varied and many including soil dwellers, defoliators, bark and timber borers, sap sackers and gall makers (Alemu Gezahegne *et al.*, 2006). Specifically, grasshoppers, crickets, beetles, termites, psyllids, wasps and cutworms hinder normal growth and production of eucalyptus trees.

Among the gall makers, the Blue Gum Chalcid (BGC) or eucalyptus (Red) Gum Chalcid is becoming one of the major insect pests on Eucalyptus trees (ICFR, 2011). *Leptocybe invasa* Fisher and La Salle (Hymenoptera: Eulophidae), which is identified by Mendel *et al.* (2004)*,* is a new gall forming invasive wasp, commonly known as BGC. It is presumed to have originated from Australia which has spread to many parts of the world where its host trees are found

(Chilima *et al*., 2017; Petro and Iddi, 2017), such as in Africa, Asia and the Pacific, Europe, North America and the Near East (Sankaran and Durst, 2017).

In Ethiopia, BGC was seen for the first time in 2000 and become a threat of *Eucalyptus* species ever since (ICFR, 2011). Giliomee (2011), on the other hand, reported that it was first seen in 2002. Despite the difference in the year of their first records, the two reports agreed that this pest has become a menace for the eucalyptus trees in the country. At the moment, BGC is a major pest of eucalyptus species mainly *E. camaldulensis*. Globally, following this aggressive BGC invasion, some management options (insecticides and cultural practices) were tried in different countries to manage the pest. For instance, chemical insecticides such as Carbofuran, Thiomethoxam, Dimethoate, Phorate, Actara, Confider, Mospilan, Imidacloprid (Hesami *et al*., 2006; Jhala *et al*., 2010; Chakrabarti, 2015; Sankaran and Durst, 2017), chemical insecticides and cultural practices (FAO, 2016) and biological and mechanical controls (Kumari *et al.,* 2010; Makaka *et al*., 2016; Nugnes *et al*., 2016; Zheng *et al*., 2016) were tested.

Currently informal reports and few studies showed that the pest is distributed in Amhara, Tigray, Oromia and Southern Nations, Nationalities and Peoples regions of Ethiopia. In the Amhara region, its distribution is reported in West Gojam, Awi zone, South Gonder, South and North Wollo and Oromia zones where eucalyptus trees are predominantly grown. Although the distribution and impact of the wasp within the different zones and districts was severe, no action was taken against the pest. Therefore, the main objective of the study was to evaluate and select different pest management options against BGC on *Eucalyptus* species in Eastern Amhara, Ethiopia.

MATERIAL AND METHODS

Description of the study area

The study area is located in Kalu district, South Wollo administrative zone, Amhara National Regional State, Ethiopia (Figure 1). Kalu is one of the main *E. camaldulensis* growing districts of South Wollo administrative zone. It is situated between 59°8'318"E longitude and 11°92'177"N latitude with an elevation of 500 to 1750 m above sea level. The district receives an average annual rainfall of 200 to 800 mm per year and annual average temperature of 17.75 °C in the low lying areas of Kalu and especially those areas close to the Afar National Regional State (KDOA, 2010).

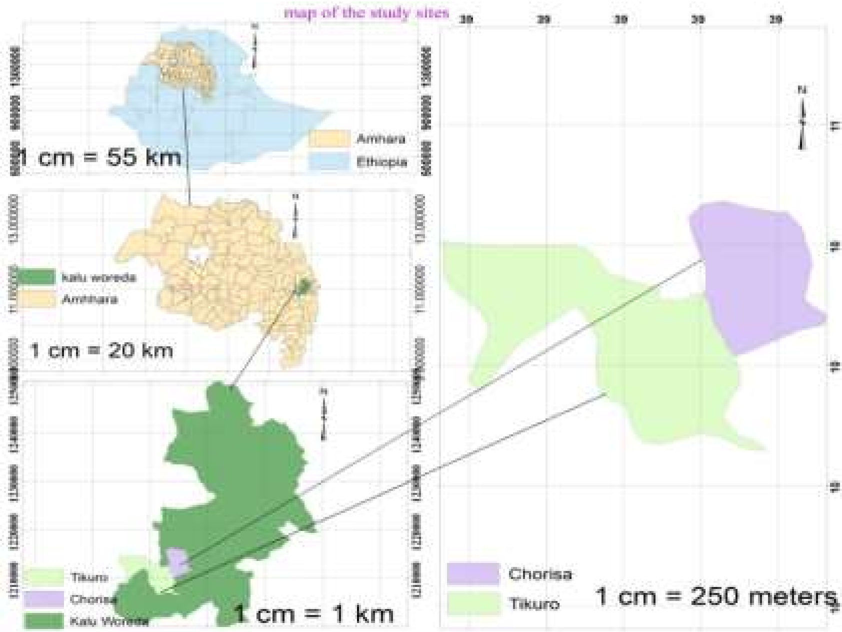

Figure 1. Map of the study area/experimental sites.

Experimental design and data collection

The experiments were conducted at nursery and field conditions. At the nursery, seven treatments (Table 1) were applied and evaluated on 4-month old seedlings of five eucalyptus species, i.e., *E. camaldulensis, E. saligna, E. viminals, E. citrodora* and *E. globulus*. Seedlings were raised using 10 cm diameter polythene tubes at Chorisa nursery in October 2018. The growing media used for raising the seedlings were forest soil, local soil and sand at a ratio of 3:1:1 mixture.

At field plantations, the study was conducted on one to three-year old *E. camaldulensis* trees because other species were not available. At Tikuro site, the study was conducted on plantations of *E. camaldulensis* trees planted by Amhara Forest Enterprise in July 2015/16 and 2017/18 trees infested by BGC insect pest were selected and assigned randomly for each treatment at the field condition. This was done due to unavailability of trees during July 2016/17. Before the first spray in all experimental plots, number of galls data was recorded. Additionally, it was also conducted on two farmer's fields of seven-month old seedlings of *E. camaldulensis* trees. The trial was laid out in RCBD with three replications.

Table 1. Treatment set up both at field and at nursery and the test species.

Treatments	At nursery	At plantation field	At farmers' plantations
	E. camaldulensis, E. saligna, E. viminals, E. citrodora, E. globulus	***E. camaldulensis***	***E. camaldulensis***
1	Dimethoate 40% E.C,	Dimethoate 40% E.C,	Dimethoate 40% E.C,
2	Thiomethoxam 25WG	Thiomethoxam 25WG	Thiomethoxam 25WG
3	Carbofuran 3G	Carbofuran 3G	Carbofuran 3G
4	Water showering	Water showering	Water showering
5	Dimethoate 40% E.C + Carbofuran 3G	Showering + hoeing	DC
6	Thiomethoxam 25WG + Carbofuran 3G	Hoeing	TC
7	Control for all	Hoeing + Dimethoate 40% E.C	Control
8	-	Hoeing + Thiomethoxam 25WG	-
9	-	Hoeing with Carbofuran 3G	-
10	-	Control	-

At the nursery, 20 seedlings, and at field 5 trees each (because of the shortage of trees) were taken as plots. Seven treatments at nursery and farmers' field, and 10 treatments at field conditions were used (Table 1). Mixed treatment of chemical insecticides was not applied at the field plantations due to shortage of trees to accommodate all the treatments. Also, hoeing/cultivation was not applied on seedlings at the nursery, because that could not be done on potted seedlings. As to the spray frequency, applications were repeated at 15-day intervals (Jhala *et al*., 2010). The rate of application was based on the manufacturer's recommendation of the insecticides (Appendix Table 1).

Between replications and between treatments, a barrier of seedlings/enough spacing at least 3 m in the field and 1 m at nursery was used; 5 cm spacing was left between seedlings within a plot at the nursery to ensure full spray coverage (Figure 2, D). Spraying was done after 3 PM in the afternoon using 5 L capacity knapsack sprayer. The insecticide was showered on trees and their branches. Spraying was done based on the crown size of the trees, whereby 2 to 4 liters of water was applied on one-year old trees and 3 to 6 liters on three-year old trees to ensure full coverage. In case of trees taller than the person who sprayed them, spraying was done by bending the trees downward. At the nursery, normal watering can was used to shower the seedlings. After conducting the first spray, the frequent watering of the seedlings at nursery was done just below the leaves, directly onto their roots. This was done with a great care, as it could wash the chemicals away if they were watered as usual, affecting their efficacy.

Figure 2. Pot preparation and seedlings at nursery.

Number of damaged and healthy leaves was recorded from 20 seedlings at the nursery and from five trees at the field. Number of galls formed was counted and recorded one day before the first spray and after 14 days. Other data on number of branches per tree, number of leaves per branch, infected and uninfected leaves/branches, number of galls per petiole, per leaf, per stem, per branch and per plant and opened and un-opened galls were counted and recorded. Each activity was photographed using photo cameras, documented, analyzed and interpreted.

Incidence and severity of infestation from the field and the nursery were calculated according to methodologies developed before (Thu *et al.*, 2009; Sankaran and Durst, 2017) (eq-1 and eq-2).

$$\text{Incidence} = \frac{\text{number of infested branches}}{\text{total number of assesed branch}} * 100 \ldots.(1);$$

$$\text{Severity} = \frac{\sum n_i \ v_i}{NV} * 100 \ldots .(2)$$

Where: ni=number of trees infested at level i, vi= severity level at level i, N=total number of assessed trees, V= maximum rating scale

Data analysis

Number of galls per leaf and number of infested leaves and infested branches were entered in Excel spread sheet ready for analysis to determine the severity of BGC infestation. The difference in number of galls between spray intervals and treatments were analyzed using SPSS software version 22.0. The data were subjected to one-way ANOVA and means separated using LSD test at $\alpha = 0.05$. Treatment means were compared separately for each spray and non- spray of each eucalyptus species.

RESULTS AND DISCUSSION

The effectiveness of different management options against the invasive gall wasp (BGC) at field plantations (one- and three-year old *E. camaldulensis* saplings) and at nursery conditions (4-months old E. *camaldulensis, E. viminalis,* and *E. saligna)* is reported here under.

Incidence and severity

From the five eucalyptus species tested at nursery site, *E. camaldulensis* and *E. viminalis* were found infested by the pest in the first four months, and *E. saligna* was found infested after five months of nursery life span. Previous studies elsewhere showed these eucalyptus species were susceptible to BGC attack (Mendel *et al.,* 2004; Roux and Slippers, 2007; Thu *et al.,* 2009; Karunaratne *et al*., 2010; Durand *et al*., 2011; TPCP, 2011; De Souza *et al.,* 2018). *Eucalyptus citrodora* and *E. globulus* were not found infested during the current study, i.e., between January and May 2019. *E. citrodora* is resistant but *E. globulus* is a host, despite the presence of some resistant clones (Thu *et al*., 2009; Durand *et al.,* 2011).

The incidence was 91.7% for *E. camaldulensis,* 76.6% for *E. saligna* and 71.7% for *E. viminalis*. One hundred percent of *E. camaldulensis* trees were found infested at the field, at the farm and at the plantations of AFE. As per Ethiopian Environment and Forest Research Institute evaluation on six eucalyptus tree species, *E. citrodora* and *E. globulus* were the ones that were found free of attack at Chorisa nursery. The severity of damage varied among the different eucalyptus species at the nursery and among the different age groups at the field conditions. *E. citrodora* and *E. globulus* were found free of attack while *E. camaldulensis* was severely damaged at the nursery site. Severity of attack on three-year old trees of *E. camaldulensis* was low. Scale of damage on younger trees varied between medium and severe at field conditions (Table 2).

Table 2. Damage severity of five eucalyptus species at Chorisa nursery and one eucalyptus species at field (Tikuro plantation of AFE and at farm-1 and farm-2).

		Incidence (%)	Severity (%)	Damage level
Nursery				
E. camaldulensis		55 (91.7)	2.33	Sever
E. citrodora		0	0	Nil
E. saligna		46 (76.6)	1.42	Medium
E. globulus		0	0	Nil
E. viminalis		43 (71.7)	1.49	Medium
Field				
E. camaldulensis at Field				
AFE plantation	1-year old	5 (100)	2.16	Sever
	3-year old	5 (100)	0.74	Low
Farm 1		5 (100)	1.03	Medium
Farm 2		5 (100)	1.28	Medium

N.B. Values in brackets are percentage of trees damaged, while these out are their numbers

Efficacy of management options against the blue gum chalcid

Nursery

Compared to water showering and the untreated check, all insecticidal treatments reduced the level of damage significantly after the 2nd spray. Dimethoate 40% E.C, Carbofuran 3G and Dimethoate 40% E.C + Carbofuran 3G were found more effective followed by Thiomethoxam 25WG + Carbofuran 3G and Thiomethoxam 25WG (Table 3).

Similar findings were also reported by Chakrabarti (2015) from India that Carbofuran 3G was found to be effective followed by Thiomethoxam 25 WG and Imidacloprid 17.8 SL, with 30 days interval between two spray sections. Additionally, Jhala *et al.* (2010) reported that Carbofuran 3G + Phosphamidon 0.04%, Carbofuran 3G + Dimethoate 40% E.C and Phorate 10G + Dimethoate 40%E.C were more effective followed by spray application of Dimethoate 40%E.C or Phosphamidon at 15-day intervals.

Table 3. Impact of management options in reducing damage of BGC on three eucalyptus species at Chorisa nursery.

Treatment	**Number of galls after each spray**			
	Before	**1st**	**2nd**	**3rd**
	E. camaldulensis			
Carbofuran 3G	6.40	5.60ᵃ	4.16ᵃ	2.32ᵇ
Dimethoate 40% E.C	6.43	5.46ᵃ	3.83ᵃ	2.13ᵃ
Thiamethoxam 25WG	5.97	5.33ᵃ	4.66ᵇᶜ	3.22ᶜ
Dimethoate 40% E.C + Carbofuran 3G	5.90	5.20ᵃ	4.10ᵃ	2.76ᵇᶜ
Thiamethoxam 25WG + Carbofuran 3G	5.60	4.93ᵃ	4.46ᵇᶜ	3.70ᶜ
Water Showering	6.13	6.50ᵇ	7.96ᶜᵈ	8.91ᵈ
Control	6.47	6.90ᵇ	8.13ᶜᵈ	9.10ᵈ
Standard error		0.26	0.25	0.22
Coefficient of variance		15.8	13.6	13.2
	E. viminalis			
Carbofuran 3G	6.03	5.40ᵃᵇ	4.13ᵃᵇ	2.83ᵇ
Dimethoate 40%E.C	5.78	4.96ᵃ	3.81ᵃ	2.43ᵃ
Thiamethoxam 25WG	5.93	5.66ᵃᵇ	4.43ᵇ	3.23ᵇᶜᵈ
Dimethoate 40%E.C + Carbofuran 3G	5.70	5.13ᵃᵇ	4.09ᵃᵇ	2.46ᵃ
Thiamethoxam 25WG + Carbofuran 3G	5.90	5.46ᵃᵇ	4.40ᵇ	3.10ᵇᶜ
Water Showering	5.97	6.40ᵇ	7.80ᶜ	8.03ᵈ
Control	5.90	6.42ᵇ	7.66ᶜ	8.16ᵈ
Standard error		0.27	0.27	0.26
Coefficient of variance		16.9	15.0	12.7
	E. saligna			
Carbofuran 3G	5.00	4.36ᵃ	2.66ᵃ	2.13ᵃ
Dimethoate 40%E.C	5.46	4.33ᵃ	2.86ᵃ	2.10ᵃ
Thiamethoxam 25WG	5.4	4.83ᵃᵇ	3.73ᵇ	3.23ᵇᶜ
Dimethoate 40%E.C + Carbofuran 3G	5.40	4.86ᵃᵇ	3.22ᵇᶜ	2.16ᵃ
Thiamethoxam 25WG + Carbofuran 3G	5.47	5.06ᵇ	3.83ᵇ	3.10ᵇ
Water Showering	5.17	5.63ᵇ	6.94ᶜ	8.43ᵈ
Control	5.03	5.60ᵇ	6.95ᶜ	8.66ᵈ
Standard error		0.23	0.22	0.24
Coefficient of variance		15.5	18.6	19.2

N.B. Analysis results of *E. citrodora* and *E. globulus* were not included, as they were not found infested fully by the insect pest.

Field conditions

Number of galls per tree significantly varied between treatments in one and 3-year old trees of *E. camaldulensis* species planted in the field. Effect of insecticidal treatments on BGC significantly varied across the different age groups of trees treated at field conditions. On one-year old *E. camaldulensis* trees, some of the insecticidal treatments significantly reduced the number of galls per leaf after the 2nd and 3rd sprays as compared to the control (Table 4).

Dimethoate 40% E.C, Carbofuran 3G, Dimethoate 40% E.C + Hoeing and Carbofuran 3G + Hoeing were found more effective treatments after the 2nd round spray and the Thiamethoxam 25WG after the 3rd round spray application. Hoeing and water showering treatments did not reduce number of galls. Therefore, reduction in number of galls on combined treatments of hoeing and insecticides was caused by the chemicals. In the three-year old plantation, no significant difference was observed on the number of galls per leaf (Table 4).

Chemical treatments did not perform better than the control on 3-year old *E. camaldulensis* trees. Carbofuran 3G was found more effective followed by Dimethoate 40% E.C in reducing the number of galls per tree. This shows that no more spray was needed for trees of three and above years, as the effect of the pest is negligible on trees that are older than three years (Mendel *et al.*, 2004; Roux and Slippers, 2007; De Souza *et al*., 2018).

Additionally, the insecticidal treatments were also tested on *E. camaldulensis* of seven-month old trees on two farmers' fields as per their request to test the chemicals in their plantations. Dimethoate 40% E.C + Carbofuran 3G, Carbofuran 3G and Dimethoate 40% E.C were found to be more effective treatments than the control and the cultural practices (Table 5).

Additional observational experiments were also made at Chorisa around the two farmers' fields, the insecticidal treatments reduced the number of galls per tree than the control/untreated and water showering. Insecticidal treatments significantly reduced the number of galls per tree. On the other hand, number of galls was high on trees where cultural practices were applied (Figure 3). Increase in number of green color galls showed increasing infestation of the BGC (Thu *et al.*, 2009; TPCP, 2011). On one-year old trees treated with Dimethoate 40% E.C, some leaves were found dry indicating phytotoxicity.

Table 4. Effect of management options on BGC on *E. camaldulensis* at the field (Tikuro plantations of AFE) condition.

Treatments	**Number of galls before and after spray**							
	1-year age				**3-year age**			
	Before	**1st**	**2nd**	**3rd**	**Before**	**1st**	**2nd**	**3rd**
Dimethoate 40% E.C	37.3	30.4a	25.7a	18.6a	78.1	72.3a	66.5a	64.2bc
Thiomethoxam 25WG	40.2	39.3b	36.3b	32.4ab	79.0	76.1b	73.9ab	68.9ab
Carbofuran 3G	36.4	28.3a	25.5a	17.7a	78.4	74.5ab	67.7a	59.8a
Water Showering	39.8	37.1ab	38.3ab	38.9bc	77.2	79.3abc	81.2bc	83.4c
Hoeing + Water Showering	42.3	42.6bc	41.9abc	39.4bc	80.1	82.4c	83.3bc	85.6bcd
Hoeing	36.4	39.4b	43.7bc	44.2c	83.3	83.8c	85.2bc	86.7bcd
Hoeing + Dimethoate 40%E.C	36.5	30.8a	26.3a	19.4a	81.2	76.3b	69.6ab	62.8ab
Hoeing + Thiomethoxam 25WG	42.1	40.3abc	36.4b	33.9ab	79.4	78.7abc	75.3ab	73.4bc
Hoeing + Carbofuran 3G	40.3	35.2ab	24.7a	18.4a	79.1	73.4a	66.8a	61.7a
Control	42.4	45.2c	49.5c	49.7bcd	82.4	87.2cd	89.1c	91.4d
Standard error of the mean		1.9	1.7	1.6		1.7	1.7	1.8
Coefficient of variation		18.0	19.4	20.3		23.8	25.2	27.9

Table 5. Effect of management options on BGC on *E. camaldulensis* at farmers' field in Chorisa.

Treatments	**Number of galls after each spray**							
	Farm 1				**Farm 2**			
	Before	**1st**	**2nd**	**3rd**	**Before**	**1st**	**2nd**	**3rd**
Dimethoate 40% E.C	12.8	11.7a	9.8a	8.3a	8.3	8.1a	7.5a	5.9ab
Thiomethoxam 25WG	13.7	13.1abc	12.4bc	11.9bc	8.3	8.3ab	7.7ab	7.0abc
Carbofuran 3G	13.8	12.6ab	10.2ab	9.4ab	8.6	8.3ab	7.4a	6.3ab
Water Showering	13.3	13.9abc	15.4c	16.4c	8.7	8.7b	8.8c	9.1d
Dimethoate 40%E.C + Carbofuran 3G	13.4	11.8a	10.6ab	8.9a	8.2	8.0a	7.7ab	5.2a
Thiamethoxam 25WG + Carbofuran 3G	13.6	12.7ab	10.4ab	9.1ab	8.4	8.3ab	8.0ab	7.5bc
Control	12.8	13.2abc	15.5c	16.6c	8.0	8.0a	8.3abc	8.5bcd
Standard error of the mean		0.22	0.31	0.41		0.19	0.21	0.32
Coefficient of variation		16.8	17.6	15.2		11.3	13.4	13.8

N.B.:- Efficacy of treatments was determined by analyzing separately for each spray sections in both farms; means in a column followed by the same letter are not significantly different.

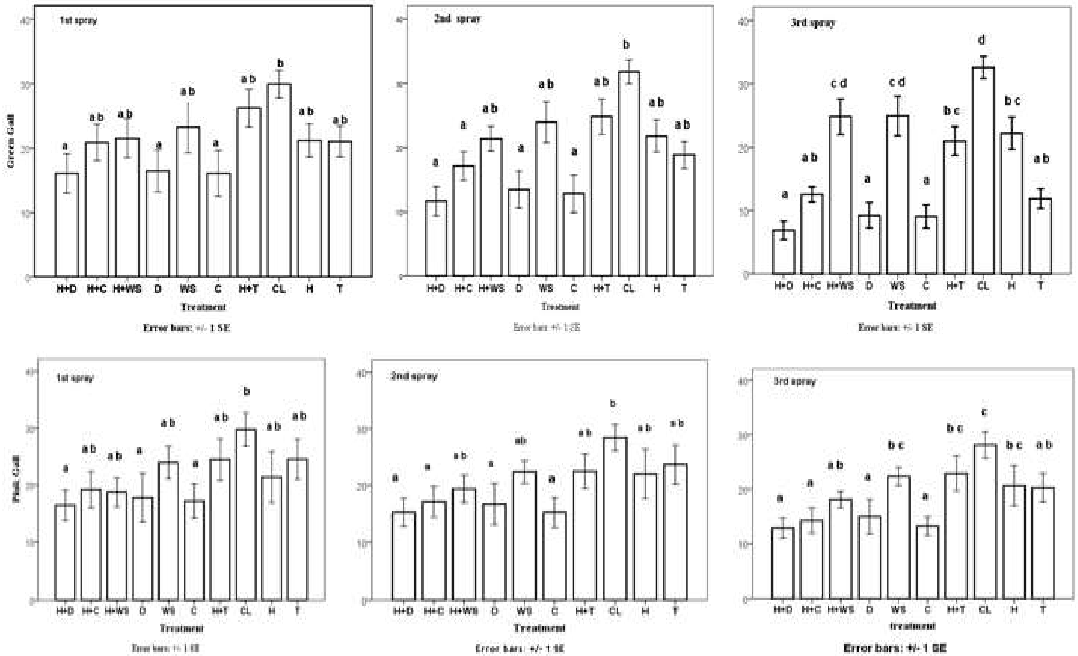

Figure 3. Effect of management options on number of green and pink color galls across the three spray intervals, in one and three-year-old age of *E. camaldulensis* at Tikuro. (Where: C= Carbofuran 3G, D=Dimethoate 40% E.C, H= hoeing, T=Thiomethoxam 25WG, CL=Control, WS=Water Showering, H+D=Hoeing + Dimethoate 40% E.C, H+C=Hoeing+ Carbofuran 3G, H+WS= Hoeing +Water Showering, H+T=Hoeing + Thiomethoxam 25WG).

Seedling injury, lack of effectiveness, or over the designated threshold of pesticide residues could result from non-uniform distribution of water (United States Environmental Protection Agency - USEPA, 2013). Therefore, great care must be taken during application to maintain uniform distribution of the insecticides in all parts of the trees.

CONCLUSION

The result of the experiment showed that at the nursery, *E. citrodora* and *E. globulus* were not prone to attack by *L. invasa*. The insecticidal treatments used were effective in protecting seedlings against *L. invasa* attack, but some of the insecticides and the cultural practices were not effective against the pest. At field conditions, application of Dimethoate 40% and Carbofuran 3G effectively checked infestations. Water showering and hoeing were not effective. At the nursery, Dimethoate 40% E.C, Carbofuran 3G and Carbofuran 3G + Dimethoate 40%E.C were more effective followed by Carbofuran 3G + Thiamethoxam 25WG and Thiamethoxam 25WG.

Among the insecticides tested against *L. invasa*, Dimethoate 40%, Carbofuran 3G and Dimethoate 40% + hoeing/cultivation could be used to manage the galls on trees older than one year. Carbofuran 3G, Dimethoate 40%E.C and Carbofuran 3G + Dimethoate 40% E.C were also good on new seedlings grown at nurseries. But no spray was needed for trees more than three years age, unless the effect was very severe, as the pest could not cause significant impact on its growth. Further investigation is required to determine rate and frequency of application of Dimethoate 40% E.C and Carbofuran 3G for the control of *L. invasa*. *E. globulus* and *E. citrodora* seedlings were not infested by the wasp during the conduct of the current experiment at the nursery. Therefore, planting less susceptible Eucalyptus species in high risk areas of infestation as well as using of recommended effective chemicals provides a potential strategy for controlling *L. invasa*. In addition, introduction of resistant species and hybrids and conducting adaptation and adoption studies is necessary in order to avoid the loss of eucalyptus plantations due to the effects of BGC.

As use of chemicals has ecological, economic and technical challenges, especially when applied by unskilled manpower; investigations on environmentally friendly alternatives (such as botanicals and bioagents) should continue to reduce or even replace synthetic pesticides. This should emphasize integrated pest management.

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Appendix Table 1. References for dose/rate, time and frequency of application of the pesticides used during the study

Chemical name	**Dose**	**Active ingredient**	**Reference for dose and active ingredient**	**References for time and frequency of application**
Dimethoate 40% E.C	1 l/ha	400 g/l	Universal Crop Protection (Pty) Ltd (Registration holder) South Africa, July 2014	(Jhala *et al*. 2010; Hesami *et al*. 2006; Sangode *et al*., 2013)
Thiomethoxam 25WG	150-200 g/ha	250 g/kg	New York State Department of Environmental Conservation, June, 2002	(Jhala *et al*. 2010; Chakrabarti, 2015)
Carbofuran 3G	4 kg/ha	100 g/kg	Universal Crop Protection Ltd (Registration holder) South Africa, April 2005	(Jhala *et al*. 2010; Chakrabarti 2015)

Note: Time of application: 5 to 6 PM; frequency of application at 15-day intervals