Diversity and invasion of insect species in mixed plantation

THESIS

Submitted to the

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

In partial fulfillment of the requirements for

the Degree of

MASTER OF SCIENCE

In

FORESTRY

(PLANTATION TECHNOLOGY)

By

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2018

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This is to certify that the thesis entitled The investigation carried out on "**Diversity and invasion of insect species in mixed plantation.**" in India and abroad have been reviewed briefly in this chapter under following sub-heading submitted in partial fulfilment of the requirement for the degree of **MASTER OF SCIENCE (Forestry) in Plantation Technology** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, is a record of the bonafide research work carried out by **Ms. Madhuri Deshmukh, I.D. no. 160107004** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.

All the assistance and help received during the course of investigation has been acknowledged by him.

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This is to certify that the thesis entitled **"Diversity and invasion of insect species in mixed plantation"** submitted by **Ms. Madhuri Deshmukh** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN FORESTRY** in **Plantation Technology** in the Department of Forestry has been, after evaluation, approved by the External Examiner and by the Student's Advisory Committee after an oral examination on the same.

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I, **Madhuri Deshmukh**, D/o Shri K. S. Deshmukh, certify the work embodies in the thesis entitled ***"*Diversity and invasion of insect species in mixed plantation*"*** is my own first hand bonafide work carried out under the guidance of Dr. R. Bajpai at Department of Forestry, College of Agriculture, Jabalpur during 2017-2018.

The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

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ACKNOWLEDGEMENT

Thanks to God and his blessing by which I was able to complete my thesis and gave me an opportunity to express my heartful gratitude to all those who have given me helping hands to make this study success.

It is pleasure for me to express my indebtness to ***Dr. R. Bajpai****, Chairperson of my advisory committee, Department of Forestry in College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India for initiating flora of research in me, continuing encouragement, insightful guidance, untiring help, keen attention, constant stimulations and constructive criticism extended all along during the investigation and for its proper presentation in the form of thesis.*

I wish to remembrance of my venerable of my advisory committee. I am grateful to ***Shri. Yashpal Singh*** *, Department of Forestry and* ***Dr. R. B. Singh****, Department of Mathematics and Agriculture Statistics for their valuable suggestions, and illuminating guidance, and generous help throughout the course of this investigation.*

I express my sincere thanks to ***Dr. S. D. Upadhyay****, Professor and Head, Department of Forestry for valuable guidance and generous help.* ***Dr. P. K. Bisen****, the Honourable Vice Chancellor****, Mr. Ashok Kumar Ingle****, Registrar,* ***Dr. Dhirendra Khare****, Director of Instruction and* ***Dr. R. M. Sahu****, Dean, College of Agriculture, Jabalpur for permitting me to complete the degree programme successfully.*

I sincerely express my appreciation and gratitude to respected teachers of Department of Forestry, ***Dr. M.L. Sahu, Dr. K.K. Jain, Shri R.P. Dongre*** *and* ***Shri Rahul Dongre*** *for their time to time suggestions, encouragement and help in various ways.*

I am thankful to the office staff and workers of Department of Forestry for needful co-operation. I also wish to express my feelings towards my batchmates ***Mukul Singh Thakur, Ajay Shah****,* ***Akash Shukla, Pooja Sharma, Brahmananda Sahoo and Anil Kori, m****y seniors* ***Dr. C.P. Rahangdale*** *and* ***Indulata Maravi,*** *my juniors* ***Parul Sharga, Kirti Rai, Kailash Mashram and Dishant Dongre*** *for their timely help and unceasing encouragement throughout the study.*

Words are not enough to express my heartiest feelings of humble gratitude indebtedness and profound sense of appreciation to my beloved Father ***Shri K.S Deshmukh ,*** *Mother* ***Smt. Veena Deshmukh****, sister* ***Harsha*** *and my brother* ***Prakash*** *for their deep love, blessings, constant inspiration and care throughout my life which enables me in my ascent to the present accomplishment.*

Place: Jabalpur
Date: …/…./ **(Madhuri deshmukh)**

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LIST OF ABBREVIATIONS

cm	=	Centimetre
mm	=	Millimetre
g	=	Gram
ml	=	Millilitre
lit	=	Litre
No.	=	Number
i.e.	=	That is
spp.	=	Species
oC	=	Degree Celsius
etc	=	Extras
et al	=	Co-workers
eg	=	As for example
ha	=	Hectare
%	=	Percent
@	=	At the rate of
viz.	=	Namely
CD	=	Critical Difference
df	=	Degree of freedom
µl	=	Micro litre
Hrs: min	=	Hours and Minute
Max.	=	Maximum
Min.	=	Minimum
RWC	=	Relative water content
ANOVA	=	Analysis of Variance

INTRODUCTION

The country's forest cover is about 78.29 million hectares or approximately 23.81% of total land cover. This includes 2.76% of tree cover. Timber is produced from naturally regenerating forests and plantation. Natural forest is supposed to be a balanced ecosystem and the damage due to the attack of insect pest and pathogens are comparatively low. Man made forest are artificial ecosystem and therefore they are more prone to damage by insect pest and disease.

Insects are the greatest destroyer of forest next to man, they damage forest to the tune of Rupees 125 Lakhs per year (Shrivastava, 1996). The annual loss caused by insects to seeds, transplant standing trees, wood and finished products has been computed to be about 10 per cent of the total revenue of the forests (David, 2001).

Among various constraints, insects are the major one, which deteriorates the quality and the quantity of trees, shrubs, herbs as well as their produce. Various types of insects have been found damaging different parts and at various growth stages such as defoliators, leaf folders, leaf webbers, leaf and stem gall makers, leaf blotch miners, fruit borers, bark borers etc.

Damaging pests and insects are found in plantation and natural forest. A fundamental concept of ecosystem dynamics is that as diversity increases, so does stability. The greater the number of plants and animals that occupy an ecosystem, the greater are the checks and balances that prevent any one species from increasing to the point where other ecosystem components are threatened. With pest and insect, the greatest single deterrent to population increase is the amount of available host.

Mixed plantations yield more diverse forest produce than monospecific stands helping to diminish farmer's risk in unstable markets. Severity of pest damage is expected to be lower in mixed plantations than in pure plantations because monospecific stands favour the spread and building up of populations of individual pests. Nevertheless there are many instance in

which pure stands are more resistant to certain pests than stands of the same species mixed with other more susceptible ones.

Insects play a vital role in tropical forest ecosystem, both from a beneficial or neutral point of view, but also as 'pests'. Insects interact at many complex levels with the trees and with the general abiotic and biotic conditions around them. A proper understanding of how such interactions bring about tree decline and death is a vital prerequisite for curing the problems.

Herbivorous insects feed on different parts i.e. leaves, woods, barks, inflorescences, roots etc. of trees and thus causing massive damage of tree health as well as timber quality. The wood and bark boring insects, mainly belonging to the orders Dictyoptera, Isoptera, Coleoptera, Lepidoptera, and Hymenoptera, bore into the wood in search of food or for shelter. Defoliators, skeletonizer and sap suckers of leaves are belong to the orders Coleoptera, Lepidoptera, Hemiptera, Thysanoptera. They feed on leaves. As a result, the surface area for photosynthesis and transpiration is greatly reduced and the growth rate of trees as well as timber quality is also reduced.

Keeping above facts in view, the present investigation entitled **“Diversity and invasion of insect species in mixed plantation”** has been proposed with following objectives:

1. To quantify the impact of invasion and insect species diversity under plantation of mixed tree species.
2. To analyze and correlate the insect pest association among various tree species.

REVIEW OF LITERATURE

The investigation carried out on "***Diversity and invasion of insect species in mixed plantation***" in India and abroad have been reviewed briefly in this chapter under following sub-heading.

2.1 To quantify the impact of invasion and insect species diversity under plantation of mixed tree species

Champion (1934) reported that continuous feeding on young teak for three successive generation in a season caused loss of about 65% of normal increment in growth and sometime even the death of defoliated sapling based on studies conducted from 1926-1931.

Beeson, (1941) recorded several leaf-eating caterpillars on *Dalbergia sissoo*. They are *Ascotis selenaria imparata*, *Enarmonia jaculatrix, Phytometra orichalcea*, *Plecoptera reflexa,* and *Anomala dalbergiae. Plecoptera reflexa* is the most harmful, causing complete defoliation. Trees stripped of their leaves remain leafless for the greater part of the growing season.

Beeson, (1941) observed leaf-eating beetles on *Dalbergia sissoo* in India and Pakistan. *Adoretus caliginosus* makes holes in the leaves between principle nerves. *Amblyrrhinus poricollis* damages foliage and *Halyzia sancrite* damages the surface of leaves. Others beetles are *Gynandropthalma quadripunctata, Illeis cincata, Mimastra cynura* and *Myllocerus pustulatus*.

MacArthur (1955) in his study clearly showed that the proximity of a mixed species stand of broad-leaved trees can effectively reduce the percentage of trees infested by *D. sylvestrella* in pure maritime pine stands, he found that the average level of infestation was lower, and pine trees close to the edge with the broad-leaved stands were less infested.

Root (1973) coined the term 'associational resistance' to describe the potential benefits of a diverse plant community which is now a widely accepted ecological concept encapsulating plant diversity effects on herbivores and their natural enemies. Associational resistance basically consists of two hypotheses, one addressing the bottom-up processes (the

resource concentration hypothesis) and the other addressing the top-down processes (the natural enemy hypothesis) both of which are likely to affect the success of a herbivorous insect in a heterogeneous habitat.

Root (1973) explained a mechanism, known as 'the natural enemies hypothesis', that is the species or populations of predators and parasitoids are more abundant in diversified ecosystems.

Gibson & Jones (1977) in their studies concluded that herbivore species, and consequently pest insects, are less abundant in diversified systems than in monocultures, they compared monocultures and mixed forests and reached a conclusion. However, some authors have pointed out that the experimental evidence to support the view is inconclusive.

Géri (1980) concluded that the processionary pine caterpillar *Thaumetopoea pityocampa* and the scale insect *Matsucoccus feytaudi* mainly damage pure maritime pine stands. On the other hand, pure and mixed stands are equally prone to the attack of many xylophagous species, such as weevils and bark beetles.

Geri and Goussard (1984) showed that attacks by the pine sawfly *Diprion pini* had a lower intensity in mixed pine and hardwood landscapes, earlier attempts focusing on this issue present very few examples from forest ecosystems, this study is one of the first providing clear experimental evidence of the beneficial effect on pest insect control of increased biodiversity in forest plantation landscapes.

Sudheendra Kumar *et al.* (1988) carried studies on seasonal incidence of *Eutectona machaeralis* in teak plantations at Nilambur, Kerala by by visual scoring of the defoliation at fortnightly intervals. During the 5-year period from 1978-1982, measurable defoliation occurred only in two years–1980 and 1981. During this period, the intensity of defoliation ranged from 14 to 40 per cent. They concluded that late season outbreak of *E. machaerclis* is an occasional but not regular phenomenon in teak plantations in Kerala and that the outbreak may be particularly heavy and wide spread in exceptional years.

Speight and Wainhouse (1989) estimated that cooley spruce gall aphid, *Adelges cooleyi*, an insect indigenous to western North America, has alternating life stages on *Picea* and *Pseudotsuga menziesii*, trees that are often found growing in close proximity to one another in natural forests.

Klimetzek (1990) indicated that the inclusion of broadleaf trees in pine forests, either as a mixture or in the understory, tends to reduce the incidence of outbreaks of *Lymantria monacha.* On the other hand, planting *Picea abies* under a plantation of *P. sylvestris*, could intensify or prolong outbreaks of this insect since both trees are hosts.

Gorpade and Patil (1991) conducted Insect pest survey in the Konkan region of Maharashtra State, they reported thirty insect–pests commonly occurring in the forest plants in this region. Among the various pests infesting the trees, termite was found to be one of the major pest of the trees at the Konkan region. The trees like karanj, shisham, khair, hirda, suru, chinch, Atrocarpas and Eucalyptus found to be infested by termite. Termites feed on the root and stem's cellulose of the bark the tree may die in severe infestation. Kalia *et al.* (2000) reported fruit sucking moth, *Achaea janata* as a new pest of *Dalbergia sissoo*. Further work on its biology is in progress.

Manion (1991) stated that some temperate zone pests and diseases have adapted to mixed-species ecosystems by having evolved life stages on alternate hosts. Many rust diseases fall into this category, including fusiform rust of *P. elliotii* and *P. taeda*, *Cronartium quercuum* f.sp. *fusiform*, which has alternate spore stages on oak, *Quercus* spp. Therefore, removal of oaks from the vicinity of pine nurseries in the southeastern USA is a common although not altogether effective practice.

Watt (1992) proposed a mechanisms to explain the effect of diversification on forest pest populations, known as 'the food source concentration hypothesis', is that the associated or adjacent plant species may prevent the pest insect locating and attacking the host species.

Wormald (1992) indicates that data on relative susceptibility of mixed and pure species plantations in subtropical and tropical regions is, at best, inclusive and confusing. While examples of where pests and diseases have

become problems in pure species plantations are cited, many result from accidental introductions or of indigenous pest species adapting to new conditions. Furthermore he cites examples where establishment of mixed species plantations has had little or no effect on reducing pest caused losses.

Sharma (1994), indicated that indigenous disease causing organisms are also capable of adapting to new hosts and causing severe damage. In Kenya, plantations of *Cupressus macrocarpa* have been severely damaged by *Monochaetia unicornis*, a stem canker causing fungus (Odera and Arap Sang 1975, 1980). During the early 1990s, several species of foliar and twig pathogens, including Cylindocladium leaf blight, Coniella leaf spot, Kirramyces leaf spot and pink disease, *Corticum salmonicolor*, damaged *Eucalyptus* plantings in Vietnam.

Walter, (1994) dealing with specific examples of insect pests, adoption and ecology must be considered in each species presents as with its own challenge which may vary with changing environmental condition from area to area and from time to time.

Chavan and Kumar (1998) observed gall midge incidence in teak clonal seed orchard and also in plantations in severe form at and around Sirsi, Karnataka. Hence survey was under taken and it was observed that the incidence of the pest was upto the extent of 20.0 to 46.0 per cent.

Kalia *et al.* (1998) stated that the fungus *Aspergillus flavus* was highly pathogenic to all the six instars, though the time taken for 100 per cent mortality of *Hyblaea puera* varied with all the instars. The first, second and third instars were found to be more susceptible to infection and died within 24-72 hrs. The mortality caused by this fungus varied from 70-80 per cent indicating high susceptibility of *H. puera* to the fungus *A. flavus*.

Mensah (1999) concluded that the considerable evidence suggests that vegetation diversity at the landscape level is often more important than the mixture of plant species at the field level in reducing pest damage and infestation.

Prasad *et al.* (2002) carried out a study on population dynamics of *Dalbergia sissoo,* defoliators *Plecoptera reflexa* and *Dichomeris eridantis* at F.R.I. Dehra Dun. They observed that the cyclic pattern in the population dynamics of defoliators of *Dalbergia sissoo* is governed by delayed density dependent factors and its growth rate.

2.2 To analyze and correlate the insect pest association among various tree species.

Rawat and Singh (2003) observed the intensity of attack in 2002 was so severe that the tree canopies had completely been defoliated as early as the second week of April. Canopy damage to this extent has not been noticed in the month of April in previous year.

Dhakal and Kjaer (2005) conducted an experiment in which they analyzed seedling seed orchard (SSO) that was heavily infested by *Aristobia horridula* a beetle that has become a sever pest infesting and killing young trees in *Dalbergia sissoo* plantings. Large and highly significant differences were found between families in mortality, showing that some progenies seem to resist the attack much better than others.

Jactel *et al*. (2005) stated the concrete example of the diversity–stability theory, which suggests that more diverse ecosystems will be more stable or more resilient to perturbations.

Ashwini *et al*. (2006) examined seasonal occurrence and activity of endemic pill millipedes (*Arthrosphaera magna*) in organically managed mixed plantation and semi-evergreen forest reserve in southwest India between November 1996 and September 1998. Abundance and biomass of millipedes were highest in both habitats during monsoon season. Soil moisture, conductivity, organic carbon, phosphate, potassium, calcium and magnesium were higher in plantation than in forest. Among the associated fauna with pill millipedes, earthworms rank first followed by soil bugs in both habitats. Since pill millipedes are sensitive to narrow ecological changes, the organic farming strategies followed in mixed plantation and commonly practiced in South India seem not deleterious for the endangered pill millipedes *Arthrosphaera* and reduce the risk of local extinctions.

Ali, *et al.* (2007) conducted a systematic study on the seasonal sequence of occurrence, incidence and maximum occurrrence of *Dalbergia sissoo* leaf blinder, *Dichomeris eridantis* Mey. In 1993. It revealed that moderate to maximum occurrence of the pest was recorded from February to October. Periodic incidence of the pest ranged from 0.30 to 10.80 in different growth maximum in the week of june 1993. The maximum temperature showed significant and positive correlation (r=0.912) with the population. Relative humidity had no significant effect.

Varma *et al.* (2007) studied the pest complex associated with intensively managed Teak plantations in the state of Tamilnadu and Andhra Pradesh, India. Besides this, the incidence and seasonal variations in insect pest populations and their occurrence were studied in relation to some environmental factors like temperature and rainfall of the mentioned area and in relation to nitrogen and phenol contents of leaf, wood and bark of the host trees.

Basu *et al.* (2010) concluded that the diversity of insect pest in mixed species plantation varies with season and with host tree species: diversity of insect pests in *Teactona grandis, Shorea robusta* and *Swietenia macrophyla* was found to be the highest at monsoon. Specifically diversity of insect pests in *Tectona grandis* both in pre-monsoon and monsoon was highest than *Shorea robusta* and *Swietenia macrophyla.*

Samuthiravelu *et al.* (2010) conducted a field experiment to study influence of abiotic factors on population dynamics of leaf webber, *Diaphania pulverulentalis* and its natural enemies in mulberry and found that the infestation of leaf webber *D. pulverulentalis* was high (17.13%) in November. The population of coccinellids and spiders was high (6.5 and 10.32/20 plants) during November. The infestation of leaf webber (above ETL of 10%) and population of its natural enemies on three varieties (local, MR2 and V1) were correlated with abiotic factors viz., temperature, relative humidity, rainfall and rainy days. Results indicated that the population of parasitoids had significant positive correlation with rainfall. The population of coccinellids, spiders and

parasitoids had positive correlation with rainy days and leaf webber infestation.

Basu *et al.* (2010) concluded that 15 different insect species fed on teak *(Tectona grandis),* 8 different species fed on sal *(Shorea robusta)* and 4 different species fed on mahogany *(Swietenia macrophyla)* in Bethuadahari, Nadia, West Bengal, India, which is a tropical moist deciduous forest. The study showed that the population density and diversity of insect pests in teak, sal and mahogany were high at monsoon season. The indigenous timber yielding tree species teak *(Tectona grandis)* is highly susceptible to insect herbivory, because leaf, wood and bark of this species possess low amount of phenol, which gave protection to the trees against insect herbivory. On the other hand, leaf, wood and bark of another indigenous species, sal (*Shorea robusta),* contained high amount of phenol, and thus it was less susceptible to insect pest attack. Mahogany *(Swietenia macrophyla)* is an exotic species in India and it is least susceptible to insect herbivory than teak and sal. Empirical results showed that leaf, wood and bark of this tree species contain little amount of nitrogen and high amount of phenol.

Jactel *et al.* (2011) concluded that the three main factors related to single-species forestry can predispose forest plantations to insect attack. First, the lack of physical or chemical barriers provided by other associated plant species could reduce access of herbivores to the large concentration of food resources, i.e., the high density of host trees in the forest monoculture. Second, the low abundance or diversity of natural enemies often observed in forest plantations can result in limited biological control of pest insects. A third factor is the potential absence of a diversion process, i.e., the disruption effect on pest insects resulting from the presence in the same stand of another more palatable host tree species.

Sahu *et al.* (2016) screened six provenances of mixed species plantation namely Raipur, Ambikapur, Jabalpur, Nainpur, Zaheerabad and Keesaragutta. He recorded various insect pests along with the number of their associated natural enemies were also recorded and concluded that the major insect pests were the common banded awl, leaf webber, leaf blotch miner,

pod borer, leaf hopper, leaf eating beetle, mealy bugs and green lace wing, mantis along with some species of spiders were observed as the natural enemies. Maximum population of common banded awl, *Hasora chromus* was recorded as 17.00 larvae/twig on Jabalpur provenance. Maximum infestation (36.3%) seeds were by pod borer, *Ephestia spp.* was recorded on Nainpur. Population of leaf webber was maximum (3.92 larvae/ twig) on Jabalpur and Keesaragutta, blotch miner (8.41 blotches/leaf) on Jabalpur, leaf eating beetles (5.25 beetles/twig) Zaheerabad, leaf hoppers 5.58 (nymphs and adults/ leaf) on Keesaragutta, mealy bugs (6.50 nymphs and adults/twig).

Kumar (2017) concluded that out of 209 insect pests that have been already recorded from all over the India, only seventeen insect pests were recorded from the Jharkhand Provence in this study on *Dalbergia sissoo*. Among these two insect pests namely, *Lawana conspersa* and *Icerya seychellarum* were recorded first time from *D. sissoo.* Reason may be due variation in vegetation, soil profile, and climatic condition, additionally, seasonal incidence of the insect pests was also found different from the earlier records. Hence, the infestation of insect pest and their seasonal incidence depends on soil type and mainly climatic condition, which may shifted with the change of climatic condition. Therefore, assessment of insect pest of major forestry species should be done at a defined interval so that epidemic of any new insect pests may be avoided.

MATERIAL AND METHODS

The experiment was carried to study the ***"Diversity and invasion of insect species in mixed plantation"*** the material used and the methods employed during the course of investigation are presented in this chapter under the appropriate heads.

3.1 Experimental site

The field experiment was conducted at Imaliya Research Farm, Department of Forestry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, (Madhya Pradesh) during September 2017 to March 2018.

3.2 Climate and weather conditions

Jabalpur is situated between 22°49' to 24°08' North latitude and 78°21' to 80°58' East Longitude with an average altitude of 411.78 meters above the mean sea level. The climate of the locality is characterized as typically semi-humid and tropical, which is featured by hot dry summer and cool dry winter. It is classified as "Kymore Plateau and Satpura Hills" agro-climate zone, as per norm of National Agricultural Research Project and is broadly known as rice-wheat crop zone of Madhya Pradesh. As per recent classification of National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Nagpur, this area belongs to agro-ecological region number 10, named as Central High Lands (Malwa and Bundelkhand), sub-region number 10.1, named as hot sub-humid (dry) eco-region (Malwa Plateau, Vindhayan Scarpland and Narmada Valley).

The mean annual rainfall of Jabalpur based on last 20 years data is 1350 mm which is mostly received from south-west monsoon between mid June to end of September with little occasional rainfall of 67.9 mm during other months. The mean monthly minimum temperature varies between 5.3 to 6.1°C in December and January, and maximum temperature varies between 40.2 to 44°C during May and June, respectively January is the coldest month of the year with minimum temperature being 5°C. Generally relative humidity remains very low during summer (20 to 23%); moderate (60 to 75%) during winter and it attains high value (80 to 95%) during rainy season.

Table 3.1: Weekly meteorological parameters during July 2017 to February 2018

Months	Week	Temperature (°C)		Relative humidity (%)		Rainfall (MM)
		Maximum	Minimum	Morning	Evening	
July	27	31.3	24.6	82	66	8.4
	28	30.3	23.6	90	81	95.2
	29	30.6	24.0	93	76	230.0
	30	28.8	22.9	90	74	86.3
Aug	31	30.6	23.9	87	68	23.0
	32	29.8	23.9	89	74	101.2
	33	30.9	23.7	87	67	7.8
	34	31.6	23.9	90	67	72.4
	35	29.8	23.7	90	65	22.0
Sep	36	32.5	24.0	88	65	1.5
	37	32.8	23.3	91	64	87.8
	38	30.7	22.4	90	73	98.3
	39	32.9	21.9	89	52	0
	40	33.4	20.3	90	51	7.4
Oct	41	32.6	21.7	92	56	9.2
	42	33.6	17.9	87	40	0
	43	33.1	15.9	81	26	0
	44	31.1	12.2	87	29	0
Nov	45	30.0	10.2	86	27	0
	46	28.9	11.9	87	42	0
	47	27.6	10.1	86	31	0
	48	28.1	05.1	82	21	0
Dec	49	26.7	08.1	80	30	0
	50	27.5	09.0	88	35	0
	51	24.8	05.5	88	32	0
	52	25.2	03.9	86	28	0
Jan	01	28.8	9.7	87	30	0
	02	24.7	12.6	88	29	0
	03	28.4	10.5	88	30	0
	04	31.0	12.7	86	25	0
Feb	05	26.7	6.8	85	28	0
	06	26.6	12.4	81	52	0

3.3 Weather conditions during the courses of investigation

Seasonal variance prevailing during the growth period play an important role on the growth and development of the any tree as well as it determines the insect pest activity on plantation.

The weekly meteorological data during the course of investigation recorded at Meteorological Observatory, Agricultural Engineering College, J.N.K.V.V., Jabalpur are presented in Table 3.1. Maximum temperature (33.6°C) was recorded in October and minimum temperature (6.8°C) in december, relative humidity ranged between 20 to 97 % in morning and 15 to 83% in evening. The total rainfall received during the period of investigation was 135.4 mm, in 9 rainy days. The wind velocity varied between 1.9 to 9.2 km per hours and mean sunshine hour ranged between 2.0 to 8.8 hours per day during six month period.

3.4 Soil:

As earlier mentioned the present investigation was the third consecutive year of experimentation at the same site. Hence, data pertaining to initial soil status of various physical-chemical properties were recorded from the soil sample taken at the time of bamboo plantation from 10 places up to a depth of 0-30 cm with the help of screw type soil auger. The soil samples were well mixed together for making representative samples. The composite samples were analyzed for physio-chemical properties of the soil in the laboratory, Department of soil science and Agricultural chemistry as per standard methods. The analytical values are presented in Table 3.2. To know the changes in chemical properties of the soil after three year of experimentation, soil samples from each plot were also taken and analyzed separately.

Table 3.2: Physical and Chemical properties of the experimental soil

Properties	Study area
Course fragment (%)	31.02
Texture class	Clay loam
Sand (%)	37.12-37.98
Sit (%)	34.02-28.46
Clay (%)	28.00-28.46
PH	6.29-8.02
EC (ds m-1)	0.05-0.25
Bulk density (g cm $^{-3}$)	0.71-1.46
Organic carbon (%)	0.83-2.96
Available N (kg\ha)	422.76-575.28
Available P_2O_5(kg\ha)	29.42-33.60
Available K_2O(kg\ha)	291.10-318.0

3.5 Technical programme of work

A field experiment was conducted on *Tectona grandis, Eucalyptus hybrid* under *Dalbergia sissoo* field. 05 treatments consisted with 1 method of planting and in Randomized block design with 4 replications. The layout plan of the experiment is depicted through the Table 3.3 and table 4.4, other details of treatment and layout plan are given below:

Table3.3 Treatments with species composition in the form of admixture and sole plantation.

Treatment	Composition
T_1	Pure *Eucalyptus* hybrid
T_2	*Eucalyptus* and *Dalbergia sissoo*
T_3	Pure *Dalbergia sissoo*
T_4	*Tectona grandis* and *Dalbergia sissoo*
T_5	Pure *Tectona grandis*

Table 3.4 Layout of mixed plantation

Replication	Treatments				
Replication 1	T_1	T_2	T_3	T_4	T_5
Replication 2	T_3	T_4	T_5	T_1	T_2
Replication 3	T_5	T_1	T_4	T_2	T_3
Replication 4	T_2	T_5	T_3	T_5	T_1

3.6 Experimental detail:

Design	Randomized Block Design
Replication	4
Treatment	5
Total no. of plots	20
No. of tree per plot	28
Total planted trees	560
Plant geometry for tree	1.5 m x 1.5 m (Row to row and Plant to plant)
Gross plot size	10.5 m x 6 m

3.7 Observations to be recorded

1. To record insect pests associated with mixed plantation at weekly intervals.
2. To study pattern of infestation and nature of damage.
3. Seasonal studies on occurrence of various insect pests.
4. To analyze and correlate insect pest association among various tree species.

3.8 Observations recorded

The details of the observation recorded and the techniques employed are described below:

3.8.1 To record insect pests associated with mixed plantation at weekly intervals

To know the distribution and association of various insect pest in Jabalpur (Research Farm under Department of Forestry, JNKVV, Jabalpur, M.P.) , mixed plantation were surveyed at weekly interval and the observation were noted for the incidence of major insect pests and minor pests on 4 randomly selected plant from each block, where each block consisting of seven trees. Ten randomly selected branches in each plant were observed for major pest.

3.8.2 Seasonal incidence and population of insect pest of mixed plantation

To note the succession and incidence of insect pest on mixed plantation the observation were recorded at weekly interval in the field condition starting from 1st week of July up to second week of February. The nature of damage of major insect pests was also studied. The meteorological data of corresponding period of observation was also noted.

3.8.3 Correlation between Insect infestation and Weather parameter (temperature, rainfall and humidity)

Weekly observations were recorded for the various insect pests. 4 plants were randomly selected from each block and observed for insect pest incidence under two canopy levels viz., upper and lower. Population of related natural enemies was also recorded. The data thus collected were correlated with the meteorological parameters.

$$\text{Coefficient (r)} = \frac{Cov(x,y)}{\sigma x\, \sigma y}$$

Where X = meteorological parameter

Y = Incidence of observation

Σ = Standard Deviation

N = number of observation

The equation of regression line of incidence of insect on metrological parameter can be obtained as follow:-

$$Y=\bar{Y}+\frac{r\sigma y}{\sigma x}(x-\bar{X})$$

Where $\frac{r\sigma y}{\sigma x}$ is estimate of regression coefficient

3.9 Statistical Analysis

In the varietals screening experiment data on the percent (%) branch infestation of moth/ caterpillar were subjected to transformation into arc sign (angular) as the case may be for analysis of variance. Data recorded on various aspects viz., insect counts, leaves branch damage etc. were tabulated and subjected to statistical analysis, by using the techniques of analysis of variance. Treatment significance difference between the treatments mean values, critical difference (CD) at 5% level of significance was computed. The data on pest population and the percentage data (leaves branch damage by various leaves infesting pests) of chemical control trail were transformed to square root and arcs in transformed values, respectively. The data thus transformed was subjected to statistical analysis for knowing the significance of different treatments.

Table 3.5. Skeleton for analysis of variance (ANOVA)

Source of variation	**D.F.**	**SS**	**MSS**	**"F" Value**		
				Calculated	**Tabulated**	
					5%	**1%**
Block	r-1	SSB	SSB/r-1= b	b/c		
Treatment	t-1	SST	SST/t-1= a	a/c		
Error (a)	(t-1)(r-1)	SSE	SSE/(t-1)(r-1) = c			
Total	(rt-1)					

$$\text{Mean sum of square (MSS)} = \frac{\text{Sum of squares}}{\text{Degree of freedom}} = \frac{\text{SS}}{\text{Df}}$$

'F' value $= \frac{Treatment\ mean\ sum\ of\ square\ (TMSS)}{Error\ mean\ sum\ of\ Squre\ (EMSS)}$

SEm$\pm$ for main treatment $= \sqrt{\frac{E(a)}{RXV}}$

CD= SEm$\pm \times \sqrt{2} \times$ t 5 % for error (a) at 12 df

CD= SEm$\pm$for sub treatment= $\sqrt{\frac{E(b)}{RXT}}$

CD= SEm$\pm \times \sqrt{2} \times$ t 5 % for error (b) at 6 df

Where:

EMS = Error mean sum of square

r = Number of replication

t = 't' table value at 5% probability level

SEm± = Standard error of mean

RESULT

The present chapter deals with findings of the investigation regarding **"Diversity and invasion of insect species in mixed plantation"** was carried out during the year 2017-18 at Imaliya research farm, Department of Forestry, College of Agriculture, J.N.K.V.V, Jabalpur. The results obtained in the present investigation were summarized in the form of tables and figures along with appendix. Data on various parameters were subjected to statistical analysis in order to draw the valid conclusions of results which are presented in succeeding pages. It has been organized according to the objectives for convenience of interpretation and presented under the following heads.

4.1. To quantify the impact of invasion and insect species diversity under plantation of mixed tree species

Studies on insect pest succession as it evident by the field incidence in five different treatment respectively revealed that about 10 species of insects (five major pests and five minor insect) species were observed to be associated with various weeks of 8 months (i.e. July to February) season on mixed species plantation at Jabalpur. (Table 4.1).

Followings were the insect species which attacked mixed species plantation and infested in various means

Table 4.1: Insect pest diversity of mixed plantation during 2017-18

S.No.	Common Name	Scientific Name	Order	Family
1.	Teak defoliator	*Hyblaea puera*	Lepidoptera	Hyblaeidae
2.	Shisham defoliator	*Plecoptera reflexa*	Lepidoptera	Noctuidae
3.	Teak skeletoniser	*Eutectona machaeralis*	Lepidoptera	Pyralidae
4.	Termites,	*Odontotermes* spp.	Isoptera	Termitidae
5.	Eucalyptus Wasp	*Leptocybe invasa*	Hymenoptera	Eulophidae
6.	Yellow spotted stink bug	*Erthesina fullo*	Hemiptera	Pentatomidae
7.	White stink bug	*Degonetus serratus*	Hemiptera	Pentatomidae
8.	Eucalyptus snout beetle	*Gonipterus scutellatus*	Coleoptera	Curculionidae

4.1.1. Teak defoliator, *Hyblaea puera* (Lepidoptera: Hyblaeidae)

The teak defoliator was present year round in teak plantations, but in varying population densities. During the period of natural defoliation of teak (November, December, January), the pest density was very low (endemic). Every year high-intensity outbreaks of teak defoliator occured immediately after the pre monsoon showers in late February. These centres are highly localized outbreaks which represents the transitional stage between very sparse endemic population and high density outbreak population. These centres will be 5,000 to 15,000 square meters in area and are characterized by heavy tree top infestation. The months of April, may, June and July witness a series of large outbreaks. During late July or September, the population declines to the endemic level.

Nature of damage

Only the larvae feed voraciously and cause significant damage to the tree thereby affecting growth and vigour of the plant. The first instar larva feeds first on the soft parenchyma of the young leaves but acquires soon the power of biting through the smaller veins and cuts a small semicircular or rectangular flap out of the edge of the leaf which it pulls over and fastens to the upper leaf surface, thus forming a small shelter inside which it lies and feeds under the folded or curled leaf edge. The whole of the green leaf tissue is destroyed by the larvae, only the largest ribs being left, with small portions of uneaten green tissue. The larva feeds within the protection and all the tissues of infested leaves are left in older leaves.

4.1.2. Termites, *Odontotermes* spp. (Isoptera: Termitidae)

Termites were found to be most common insects among others which infested all the three species. Termites predominantly damaged Eucalyptus. Termites are usually small, measuring between 4 to 15 millimeters (0.16 to 0.59 in) in length. The three basic segments of a termite antenna include a scape, a pedicel, and the flagellum. The mouth parts contain a maxillae, a labium, and a set of mandibles. Consistent with all insects, the anatomy of the termite thorax consists of three segments: the prothorax, the mesothorax and the metathorax.

Nature of damage

Termites cause significant damage to eucalyptus individuals, shoot, root or soil termites attack the shoot and roots of eucalyptus trees, causing girdling of shoot and destroying the root system. The buds develop calluses from resisting termite attack, which decreases the economic value of the tree. Heartwood termites attack trees 2-years-old or older by hollowing and destroying the inner portion of the tree. Powder like material deposited at the base of the trunk.

4.1.3. Shisham defoliator, *Plecoptera reflexa* (Lepidoptera: Noctuidae)

The pest appeared first in the end of March, in April the pest is present in small numbers and the infestation is almost sporadic. Most severe defoliation is noticeable by the end of April or early May, causing almost complete defoliation and continue till the end of August. From the end of August there was seen a sharp decline in the abundance of *Plecoptera* population due to increased atmospheric humidity. The last brood went into hibernation in October.

Nature of damage

The newly hatched young larvae feed on the lower epidermal end inner tissues of the young, tender and unfolding leaves, leaving the upper epidermal layer intact. The latter instars become voracious feeders, devouring all the tissues, including the petioles and green shoots. After repeated defoliations, the effected plants exhibit symptoms of die-back in tips and leading shoots, producing epicormic and bushy branches.

4.1.4. Teak skeletonizer, *Eutectona machaeralis* (Lepidoptera, Pyralidae)

The presence of this species was found from July to December, with maximum catches during the months of August to October. Larvae caused skeletonization of leaves. The conspicuous seasonal abundance of *E. machaeralis* and the likely epidermic defoliation in pure teak crops are largely determined by the climatic conditions of a locality, but unlike *H. puera*, not so much on the quality of the food.

Nature of damage

The overall impact of severe defoliation results in a state of more or less leaflessness during most of the growing period. Complete defoliation is caused by the first brood or by any one of the subsequent broods.

4.1.5. Eucalyptus snout beetle, *Gonipterus scutellatus* (Coleoptera, Curculionidae)

The abundance of pest heavily noticed in the month of July to September, favourable by lowering temperature and high humidity. The impact and overall population of larvae and adults was seen more in pure treatments than in the mixed one.

Nature of damage

Both the adult and the larvae feed on the leaves and fresh shoots of susceptible species; the larvae did the worst damage by destroying the leaf epidermis. Eggs are laid on young leaves and there were usually two generation during a year.

4.1.6. Eucalyptus Wasp, *Leptocybe invasa* (Hymenoptera, Eulophidae)

An invasive eulophid wasp species whose adult female oviposit in young meristems, which include midribs of juvenile leaves. Oviposition scars were visible on both sides of the midribs, particularly on tender leaves. As the egg hatched, the larvae developed inside the plant tissue within the larval chamber, deriving its nutrition from the surrounding plant tissue. Characteristically cylindrical galls developed on either young stems or petioles or midribs. Mature galls are usually deep pink or red. Pupation also occurred within galls and adult wasps emerge by cutting a hole through the gall wall.

Nature of damage

Gall formation occurred. Infested growing shoot terminals and midribs enlarged in thickness and leaves present a contorted appearance. New leaves appearing from the gall infested shoot terminals are used to be generally stunted. As adults emerged, shoot terminals and leaves become dry, resulting in retarded growth, poor stem form and loss of vigour in susceptible eucalyptus clones and seedlings.

4.1.7. Yellow spotted stink bug, *Erthesina fullo* (Hemiptera, Pentatomidae)

The insect priorly attacks teak, spends winter in the adult stage, sometimes under bark or in natural crevices, and becomes active again during the warm sunny day. The colour of the adult resembles with the tree trunk making it difficult to find out.

Nature of damage

The stick bus feeds upon bark and trunk of the tree and sucks sap. The infestation of pest reduces the quality of wood making economic losses.

4.1.8. White stink bug, *Degonetus serratus* (Hemiptera, Pentatomidae)

The pest primarily attacks upon teak and infest throughout the year, it is hardly affected by weather conditions though its activity becomes instinct in summer.

Nature of Damage

Its adult primarily attacks on trunk and bark while nymph suck sap of young shoots and upper epidermis of leaves. Though the population remains stagnant and steady the damage caused is not severe. The prior defoliation follows a setback which results into coming up of new shoots.

Table 4.2 Occurrence of insect pests in various treatments.

No.	Species of insect	Treatments
1	Teak defoliator	T_4, T_5
2	Termites	T_1, T_2, T_3, T_4, T_5
3	Shisham defoliator	T_3, T_2, T_4
4	Teak skeletonizer	T_4, T_5
5	Eucalyptus snout beetle	T_1 T_2
6	Eucalyptus Wasp	T_1, T_2
7	Yellow spotted stink bug	T_4, T_5
8	White stink bug	T_4, T_5

Table 4.3 Mean population of insect on various treatments of mixed plantation

Name of insect / Treatments	Teak defoliator	Termites	Shisham defoliator	Teak skeletonizer	Eucalyptus snout beetle
T_1	0	11.88	0	0	7.13
T_2	0	8.58	0	0	6.20
T_3	0	6.94	3.18	0	0
T_4	4.79	7.16	4.98	4.89	0
T_5	7.54	8.30	5.81	6.05	0
SEm±	**0.17**	**0.58**	**0.29**	**0.22**	**0.35**
CD (P=0.05%)	**0.54**	**1.79**	**0.89**	**0.66**	**1.08**

Table 4.4 Mean population of insect on various treatments of mixed plantation

Name of insect / Treatments	Eucalyptus Wasp	Yellow spotted stink bug	White stink bug
T_1	4.17	0	0
T_2	3.50	0	0
T_3	0	0	0
T_4	0	5.39	2.96
T_5	0	7.35	4.01
SEm±	**0.19**	**0.34**	**0.29**
CD (P=0.05%)	**0.59**	**1.06**	**0.90**

4.2. Correlation of different weather parameters with population dynamics of different insect pest in mixed plantation

Some weather parameter exhibited positive correlation and some exhibited negative correlation. Positive correlation indicates that population of insect increases with weather parameter and negative correlation indicates population of insect decreases with weather parameter.

4.2.1. Teak defoliator, *Hyblaea puera* (Lepidoptera: Hyblaeidae)

The correlation analysis of teak defoliator was found to be significantly negative with maximum temperature (-0.914) as well as minimum temperature (-0.916). While the relative humidity (morning), relative humidity (evening) and rainfall were found to be negative correlated i.e. -0.639, -0.803, 0.615 respectively with statically non-significant.

4.2.2. Termites, *Odontotermes* spp. (Isoptera: Termitidae)

The correlation analysis of termite non-significant and negative correlation with maximum temperature (-0.019) and with minimum temperature (0.582) it is said to be positive correlated. While with both the relative humidity (morning) and relative humidity (evening) the correlation is positive and non-significant respectively with 0.582, 0.513.

4.2.3. Shisham defoliator, *Plecoptera reflexa* (Lepidoptera: Noctuidae)

The correlation analysis of shisham defoliator showed a significantly negative correlation with the minimum temperature (-0.949), relative humidity in morning (-0.777), relative humidity in the evening (-0.991), and rainfall (-0.904), correlation analysis of shisham defoliator with maximum temperature (-0.560) and was found statically non-significant.

4.2.4. Teak skeletonizer, *Eutectona machaeralis* (Lepidoptera, Pyralidae)

The correlation analysis of teak skeletonizer showed a significantly negative correlation with maximum temperature (-0.919), minimum temperature (-0.945) and while with the morning relative humidity (-0.731), evening relative humidity (-0.822) and rainfall (-0.634) with statistically non-significant.

4.2.5. Eucalyptus snout beetle, *Gonipterus scutellatus* (Coleoptera, Curculionidae)

The correlation analysis of eucalyptus snout beetle with maximum temperature (0.325) was positive but not significant, and of minimum temperature (0.856) with positive non-significant. The insect showed positive correlation with morning humidity (0.742) non-significant, while evening relative humidity (0.968) shows positive correlation and statistically significant. The correlation with rainfall was found to be positively significant i.e. 0.958.

4.2.6. Eucalyptus Wasp, *Leptocybe invasa* (Hymenoptera, Eulophidae)

The correlation analysis of eucalyptus wasp showed a positive and non-significant with maximum temperature (0.320) and with minimum temperature (0.855). The correlation analysis showed a positive correlation with morning relative humidity (0.736) but it was statistically found to be non-significant, correlation analysis with evening relative humidity (0.969) and rainfall (0.964) and statistically found significant.

4.2.7. Yellow spotted stink bug, *Erthesina fullo* (Hemiptera, Pentatomidae)

The correlation analysis of yellow spotted stink bug showed a negatively significant relation with maximum temperature (-0.919) and with the minimum temperature (-0.935) statistically significant, the correlation analysis of morning as well as evening relative humidity were negatively non-significant with the value (-0.694) and (-0.816) respectively while correlation of the abundance of the insect with rainfall (-0.627) was found to be negative nonsignificant

4.2.8. White stink bug, *Degonetus serratus* (Hemiptera, Pentatomidae)

The correlation analysis of white stink bug showed a negative but significant relation with maximum temperature (-0.919) and with minimum temperature (-0.936), while morning relative humidity (-0.697) and evening relative humidity (-0.817) both are negatively correlated with statistically non-significant. The rainfall (-0.628) is negatively correlated.

Table 4.5 Correlation matrix of different weather parameters with population dynamics of different insect pest in mixed plantation

Name of insect	Weather parameters				
	Max. Temperature (0C)	Min. Temperature (0C)	Morning R.H. (%)	Evening R.H. (%)	Rainfall (mm)
Teak defoliator	-0.914*	-0.916*	-0.639	-0.803	0.615
Termites	-0.019	0.582	0.513	0.753	0.924*
Shisham defoliator	-0.560	-0.949*	-0.777	-0.991**	-0.904*
Teak skeletonizer	-0.919*	-0.945*	-0.731	-0.822	0.634
Eucalyptus snout beetle	0.325	0.856	0.742	0.968**	0.958*
Eucalyptus Wasp	0.320	0.855	0.736	0.969**	0.964**
Yellow spotted stink bug	-0.919*	-0.935*	-0.694	-0.816	-0.627
White stink bug	-0.919*	-0.936*	-0.697	-0.817	-0.628

Note: * and ** sign indicates significant at 0.05 and 0.01 level of significance respectively

DISCUSSION

Admixture or mixed plantation refers to woody perennials that are deliberately grown so as to make more than one significant contribution to the production and service function of land use systems. Insect and pests are greatest threat to these plantation as they affect them directly as well as indirectly.

The risk of pest damage in forest expands world-wide and sustainable management is becoming a general goal. Numerous studies have demonstrated that pest insect are less abundant in more diverse mixed plantation but limited experimental evidence exists for a similar relationship in forestry. But plantation forests are usually mosaics of single was to test the effect of tree mixture at a landscape level on pest insect infestation (Jactel et. al. 1996).

Recent studies indicate that diversity in habitat structure (Denis 1997) or in habitat quality at the landscape level often affects insect species diversity, including predators and parasitoids. The natural enemies recorded in the course of study were namely, Praying mantis (*Mantoida fulgidipennis*) family- Mantoididae; and Stripped beetle (*Brumoides suturalis*) family- Coccinellidae. Some incidence has demonstrated that increasing habitat diversity in mixed plantation may prevent the development of defoliator outbreak (Geri and Gouscard, 1984).

The results of the study clearly indicates that treatments with only species are more prone to insect and pest invasion than those which are mixed one. A fundamental concept of ecosystem dynamics is that as diversity increases, so does stability. The greater the number of plants and animals that occupy an ecosystem, the greater are the checks and balances that prevent any one species from increasing to the point where other ecosystem components are threatened. The relative lack of pest out breaks in mixed tropical forests is often cited as evidence for the importance of diversity in stabilizing plant communities (Speight and Wainhouse, 1989).

5.1 Insect pest recorded on mixed plantation

Ten species of insect were recorded in mixed plantation out of which five species of insect were classified as major pests while five species were classified as minor insect pest. The identification of insects was done at Forest Entomology Division, Tropical Forest Research Institute, Jabalpur, Madhya Pradesh.

The major insects recorded were teak defoliator, teak skeletonizer, termite, praying mantis and stripped beetle whereas, minor insect pests of mixed plantation recorded were shisham defoliator, eucalyptus snout beetle, eucalyptus wasp, yellow stink bug, white stink bug. Similar results were also reported by Sahu *et. al*. (2016) recorded in twenty two provenances of mixed species plantation, common major pest were leaf minor, leaf hopper, pod borer, leaf eating beetle etc.

Among major insect pests of mixed plantation maximum population recorded was of termites, it was followed by praying mantis, stripped beetle, teak defoliator and teak skeletonizer respectively in descending order, while in minor insect pests, eucalyptus wasp, white stink bug, eucalyptus snout beetle, shisham defoliator and yellow stink bug was observed in descending order respectively.

The result of the study revealed that pure treatments with only one species are more prone to insect and pest infestation than the mixed stands. Treatment with sole crop (T_1, T_2, T_5) were subjected to higher invasion of insect pest, than the treatments with dual or mixed crop i.e. (T_2, and T_4). Similar results were also reported by Sudheendra Kumar *et.al* (1988) by visual scoring of teak skeletonizer on pure and mixed plantation, the study showed a sharp decline in insect population in mixed stands, as compared to pure stands.

5.2 Seasonal incidence and population dynamics

The damage occurred is mostly tunneling and leaf defoliation. The maximum damage was caused by termites, followed by praying mantis, stripped beetle, yellow spotted stink bug, shisham defoliator, eucalyptus snout beetle, white stink bug, and teak defoliator, wasp and teak skeletonizer was found to be minimum by visual observation.

The result revealed that the pest incidence was maximum in the month of September followed by February and March, respectively. The pest incidence was maximum in the month of December, November and February. The activity of teak defoliator was started from the last week June, followed by July, maximum population of teak defoliator was seen during the months of September.

Termite was one of the most common insect being observed. The declination was observed in population in the rainy season. Appearance of shisham defoliator was first seen in the end of March. A sharp decline in population was seen from the last week of August. Teak skeletonizer mostly appeared during raining season in the months of August to September,. Hence, most of the insect were seen in outbreak in the rainy season, starting from late June until end of September, this followed by a less population in month of October, and in February.

5.3 Statistically significant data

Correlation analysis of weather parameter and insect population revealed that occurrence of insect pests exhibited a degree of association with various weather parameters. Maximum temperature was found to be negatively significant with most of insect pests, same as morning and evening relative humidity were also found to be negatively significant with the insect pest population. Rainfall was found to be positively significant with insects which infested teak (Table: 4.5). Therefore, the correlation study shows that there is considerable effect of weather parameter on insect population.

The activity of teak defoliator was started from onset of monsoon and continued till October and the maximum population was observed in the month September as it exhibits a significant positive correlation with rainfall (0.615). With morning and evening relatively humidity, there was negatively significant correlation (-0.639 and -0.803). Therefore it shows that the incidence of insect decreases if relative humidity increases.

The correlation analysis of termite shows non-significant and negative correlation with maximum temperature (-0.019), while with both the relative

humidity (morning) and relative humidity (evening) the correlation is positive and non-significant.

The correlation analysis of eucalyptus snout beetle and eucalyptus wasp the correlation analysis shows highly positive and non-significant with morning relative humidity (0.742 and 0.736) and evening relative humidity (0.968 and 0.969 at 0.1 % level).

The correlation analysis of rest of the insect species with weather parameter shows negative, both significant and non-significant as well. It is appropriate that the insect pest association with various tree species varies greatly with the composition and combination of different tree species in a plantation. Evidently the quantity of invasion in mixed plantation was found to be less abundant than the pure plantation.

SUMMARY, CONCLUSION AND SUGGESTIONS

FOR FURTHERWORK

6.1 Summary

The present investigation entitled **"Diversity and invasion of insect species in mixed plantation"** was conducted at Imaliya Research Farm, Department of Forestry, College of Agriculture, JNKVV, Jabalpur (MP) during the year 2017-18. The experimental material consisting of three species namely *Eucalyptus* hybrid, *Tectona grandis*, and *Dalbergia sissoo*, which were planted in five different pure and mixed treatments at 1.5 m to 1.5 m spacing in Randomized Block Design (RBD) with four replications. Each treatment consisted of 4 rows with 7 plants. Total number of seedlings planted in the year 2006-07 was 560 and during the present course of investigation year 2017-18, only 328 plants were survived out of 560.

The study was conducted to quantify the intensity of damage, impact of invasion caused by pests, their correlation and association among various tree species in a mixed plantation.

Mixed plantation is the need of the hour as they produce more biomass and prove to be more productive than the pure stands. Mixed plantation flourishes communal needs such as timber, smallwood, fuelwood, pulpwood, fodder, and other useful products. Insects and pests proved to be the limiting factor in success of a plantation, the damage caused by insect pest is worth millions. Such losses cannot be averted completely but could be limited to certain extent by adopting certain crop composition and combination theories such as mixed plantation and intercropping. The mixed plantation at the experimental plot is an ideal one consisting of a fast growing species (eucalyptus) that proposes early returns, a leguminous species (shisham) that fixes the atmospheric nitrogen into soil making it nutrient rich and an economically valuable species (teak).

The present study revealed that teak defoliator, termite, shisham defoliator, teak skeletonizer, eucalyptus snout beetle, eucalyptus wasp, yellow spotted stink bug and white stink bug, were the insects associated with mixed

plantation. Most of the insect were found in the month of September, followed by an outbreak in February and March.

The analysis of variance revealed that maximum infestation of insects recorded during the period of observation was in treatment T_5 followed by T_4, T_3, T_1, and T_2. Comparing the insect population treatment wise it is concluded that the infestation in T_1 (Eucalyptus) is more than T_2 (Eucalyptus + Shisham), similarly infestation in T_3 (Shisham) is more than T_2 (Eucalyptus + Shisham), infestation in T_3 (Shisham) is more than T_4 (Teak + Shisham) and infestation in T_5 (Teak) is more than T_4 (Teak + Shisham).

The correlation analysis revealed that rainfall was found to be positively significant with most of the insect pest occurrence, while morning and evening relative humidity were negatively non-significant with the insect pest occurrence. Maximum and minimum temperature was negatively significant with most of the insect species.

6.2 Conclusions

Based on the results the following conclusions are drawn from the present investigation:-

1. Various species of insect pest observed on the mixed plantation were teak defoliator, termite, shisham defoliator, teak skeletonizer, eucalyptus snout beetle, eucalyptus wasp, yellow spotted stink bug and white stink bug.
2. There were considerable effect of weather parameter on insect population, evening and morning relative humidity was negatively correlated with most insect pest except termite, eucalyptus snout beetle and eucalyptus wasp. The rainfall was positively correlated with insects like teak defoliator, teak skeletonizer and termite.
3. Termite and teak defoliator caused maximum damage to the plantation.
4. Pure treatments were tend to be more susceptible to insect invasion and insect damage as compared to mixed treatment or stand containing more than one species.

6.3 Suggestions for further work

1. Studies on predators, parasites and parasitoids should be done more intensively.
2. A detailed study with reference to Integrated Pest Management should be carried out on mitigation of damage caused by insect pests identified in mixed plantation.
3. Screening of treatments against insect pest should be done with more parameters like biomass, economic feasibility and utilization.
4. Study on insect pest damage susceptibility should be done treatment wise.

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APPENDIX- I

Insect pest observed on different treatments of mixed plantation

S.No.	Comman Name	Scientific Name	Order	Family
1.	Teak defoliator	*Hyblaea puera*	Lepidoptera	Hyblaeidae
2.	Termites	*Odontotermes* spp.	Isoptera	Termitidae
3.	Shisham defoliator	*Plecoptera reflexa*	Lepidoptera	Noctuidae
4.	Teak skeletoniser	*Eutectona machaeralis*	Lepidoptera	Pyralidae
5.	Eucalyptus snout beetle	*Gonipterus scutellatus*	Coleoptera	Curculionidae
6.	Eucalyptus Wasp	*Leptocybe invasa*	Hymenoptera	Eulophidae
7.	Yellow spotted stink bug	*Erthesina fullo*	Hemiptera	Pentatomidae
8.	White stink bug	*Degonetus serratus*	Hemiptera	Pentatomidae

CURRICULAM VITAE

Name of the author- Madhuri Deshmukh

Place- Seoni (M.P.)

Date of Birth- 23rd July 1993

The author of this thesis Madhuri Deshmukh D/o Shri. Khyal Singh Deshmukh was born on 23th July 1993 at Seoni (Madhya Pradesh). She has joined the following institutions and successfully completed the degree of M.Sc. (Forestry) during the year 2017-18.

S. No.	Institutions
1	JNKVV, Jabalpur (M.P)
2	JNKVV, Jabalpur (M.P.)
3	Govt. Multipurpose H.S. Excellence School Seoni (M.P.)
4	Govt. Multipurpose H.S. Excellence School Seoni (M.P.)

She has got the following degrees,

S. No.	Degree granted	University/Board	Year
1	M.Sc. (Forestry)	JNKVV, Jabalpur	2018
2	B.Sc. (Forestry)	JNKVV, Jabalpur	2016
3	12th	M.P. Board	2011
4	10th	M.P. Board	2009

She has following scientific interests-

Scientific interests

a. Forestry

b. Wildlife Management

c. Public Administration

Award

Participated and obtained winning certificate in various inter and intra college cultural competition and sports competition during B.sc. (Forestry). For the partial fulfilment of the master's degree programme she was allotted a research problem on "**Diversity and invasion of insect species in mixed plantation"** which was successfully conducted by her and being submitted in the form of the thesis.

Plate 1. <u>Overview of the experimental field</u>

Plate 2. <u>Handling & Collection of Insec</u>

Plate 3.1: Teak defoliator

3.2: Narure of damage

Plate 3: <u>Insect pest in mixed plantation</u>

Plate 4.1: Termite

Plate 4.2: Nature of damage

Plate 4: <u>Insect pest of mixed plantation</u>

Plate 5.1: Shisham defoliator

Plate 5.2: Nature of damage

Plate 5: <u>Insect pest of mixed plantation</u>

Plate 6.1: Eucalyptus snout beetle

Plate 6.2: Nature of damage

Plate 6: <u>Insect pest of mixed plantation</u>

Plate 7.1: Eucalyptus wasp

Plate 7.2: Nature of damage

Plate 7: <u>Insect pest of mixed plantation</u>

Plate 8.1: Yellow stink bug

Plate 8.2: Nature of damage

Plate 8: <u>Insect pest of mixed plantation</u>

Plate 9.1: White stink bug

Plate 9.2: Nature of damage

Plate 9.3: Stripped beetle

Plate 9.4: Nature of damage

Plate 9.5: Praying mantis

Plate 9. <u>Various insect pest of mixed plantation</u>

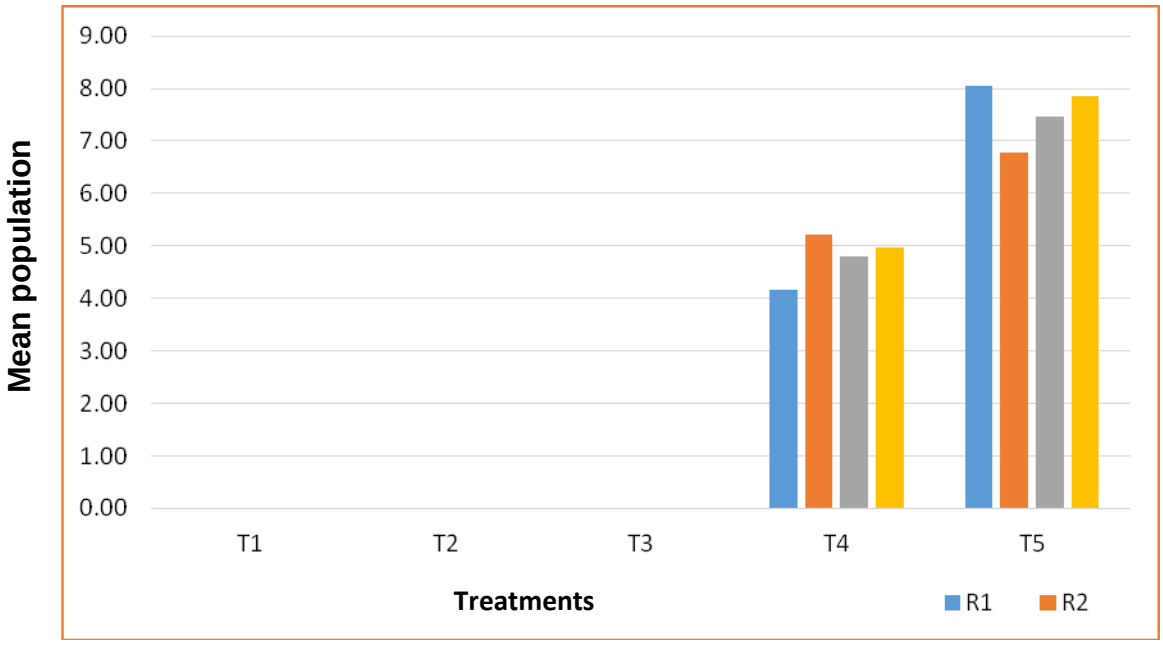

Figure 1. Population of Teak defoliator in various treatments

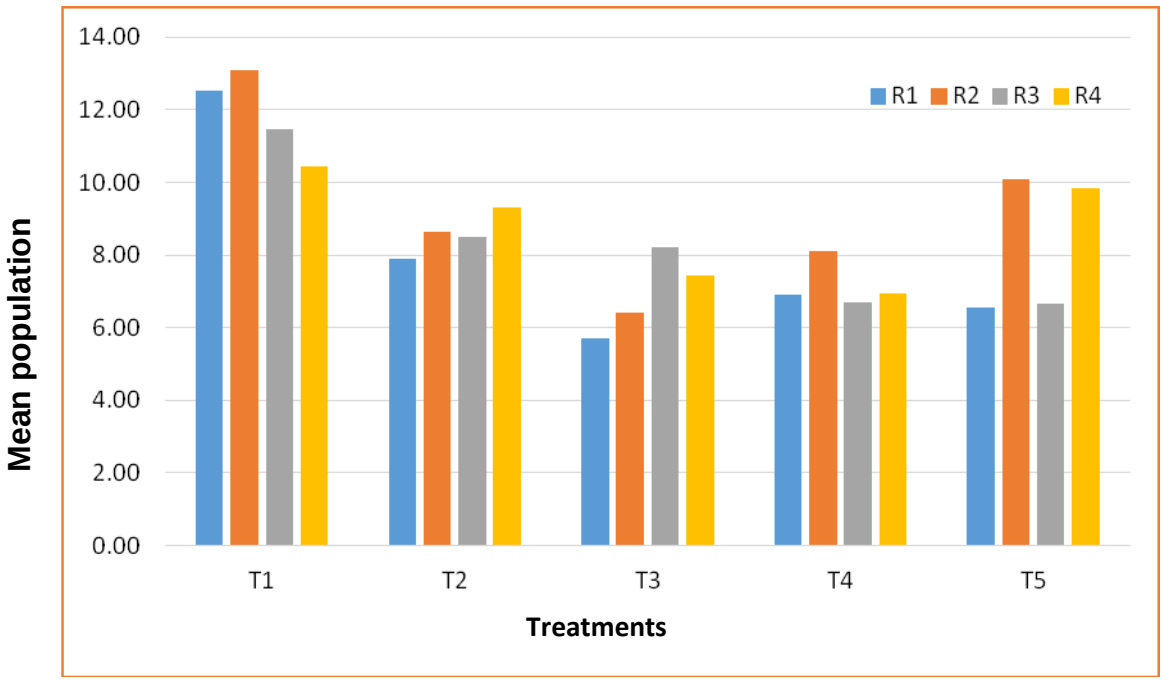

Figure 2. Population of termite in various treatments

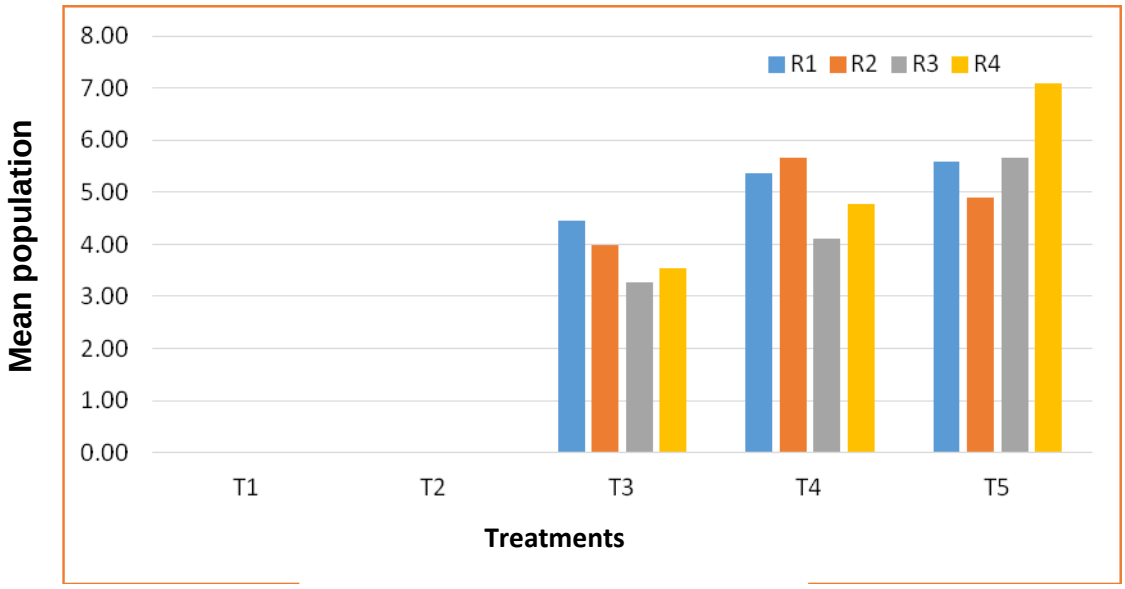

Figure 3. Population of shisham defoliator in various treatments

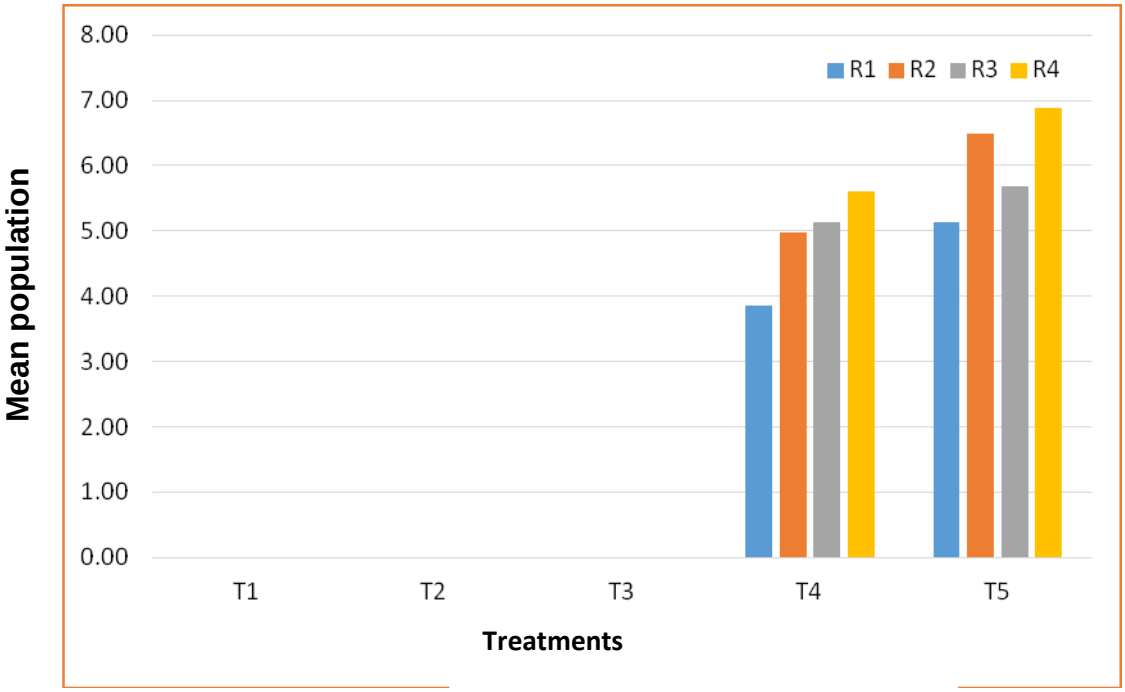

Figure 4. Population of teak skeletonizer in various treatments

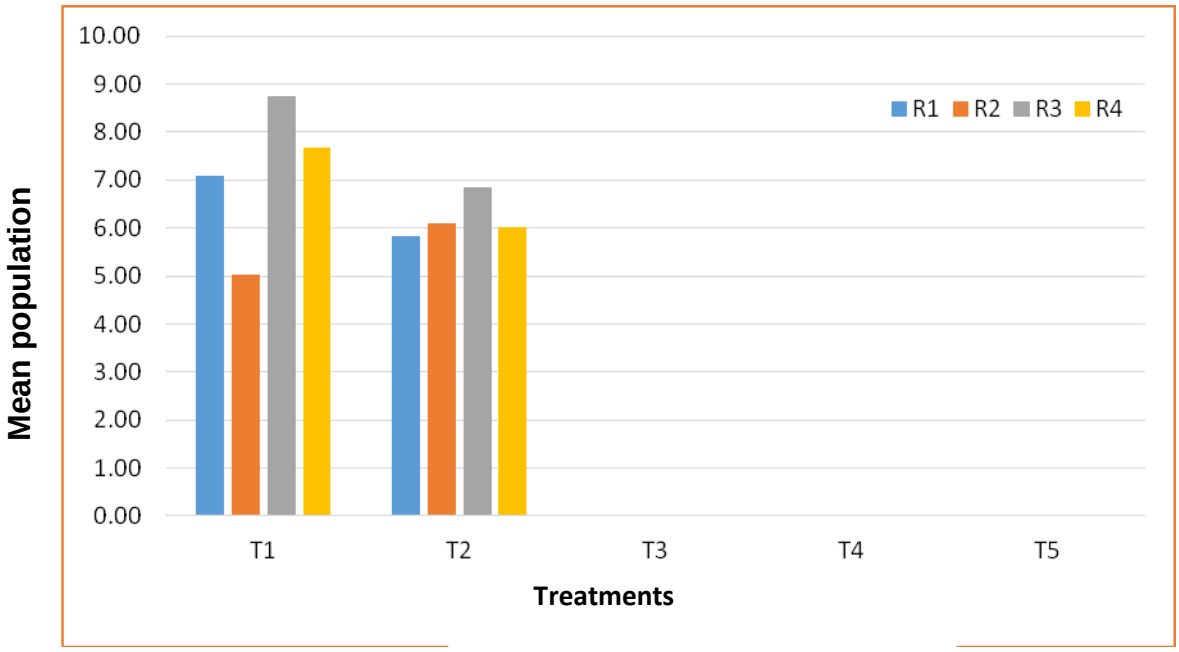

Figure 5. Population of Eucalyptus snout beetle in various treatments

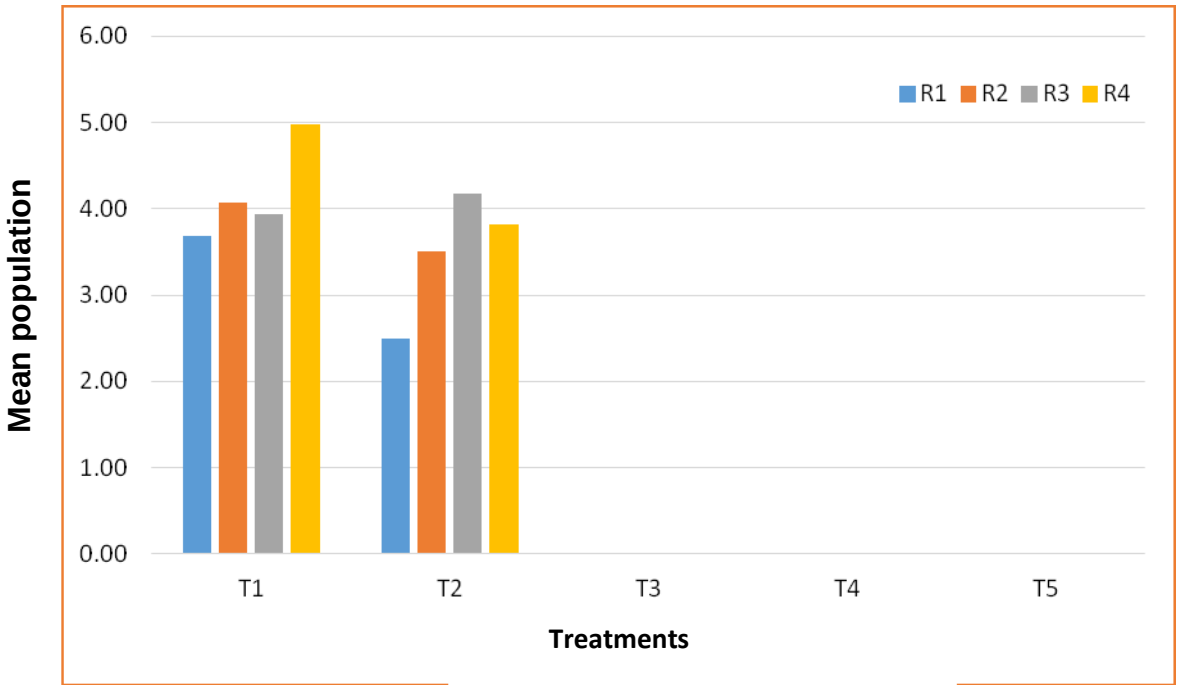

Figure 6. Population of Eucalyptus wasp in various treatments

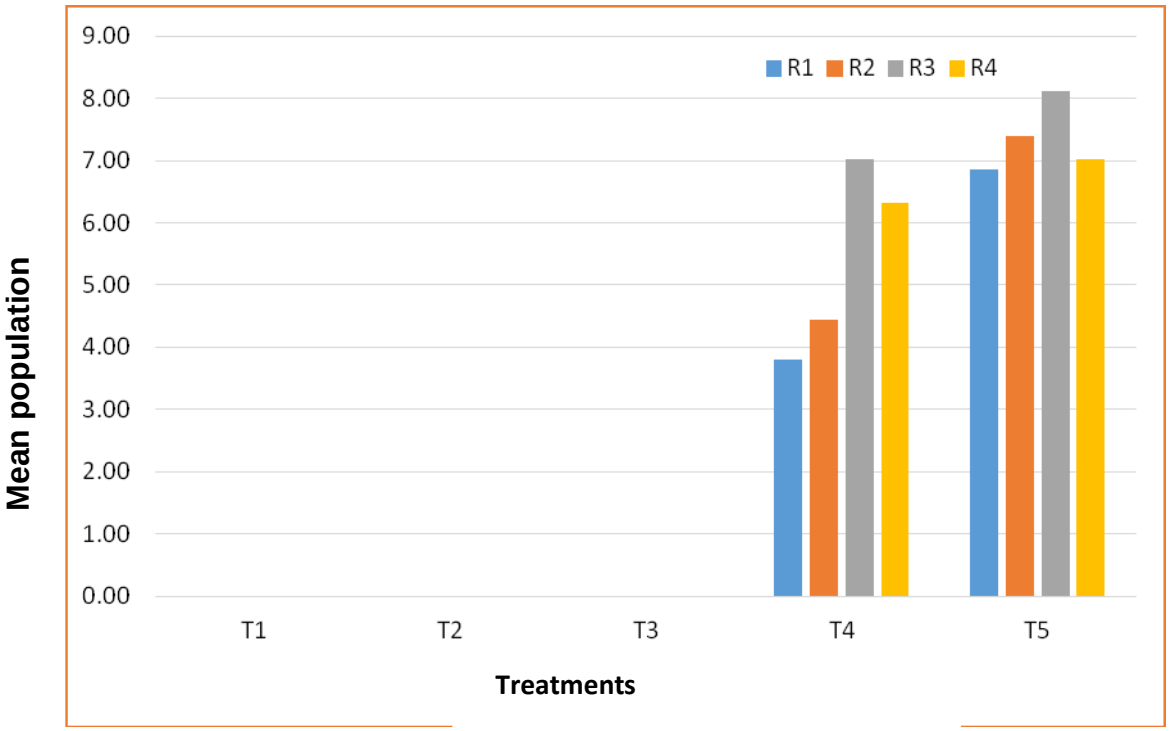

Figure 7. Population of yellow stink bug in various treatments

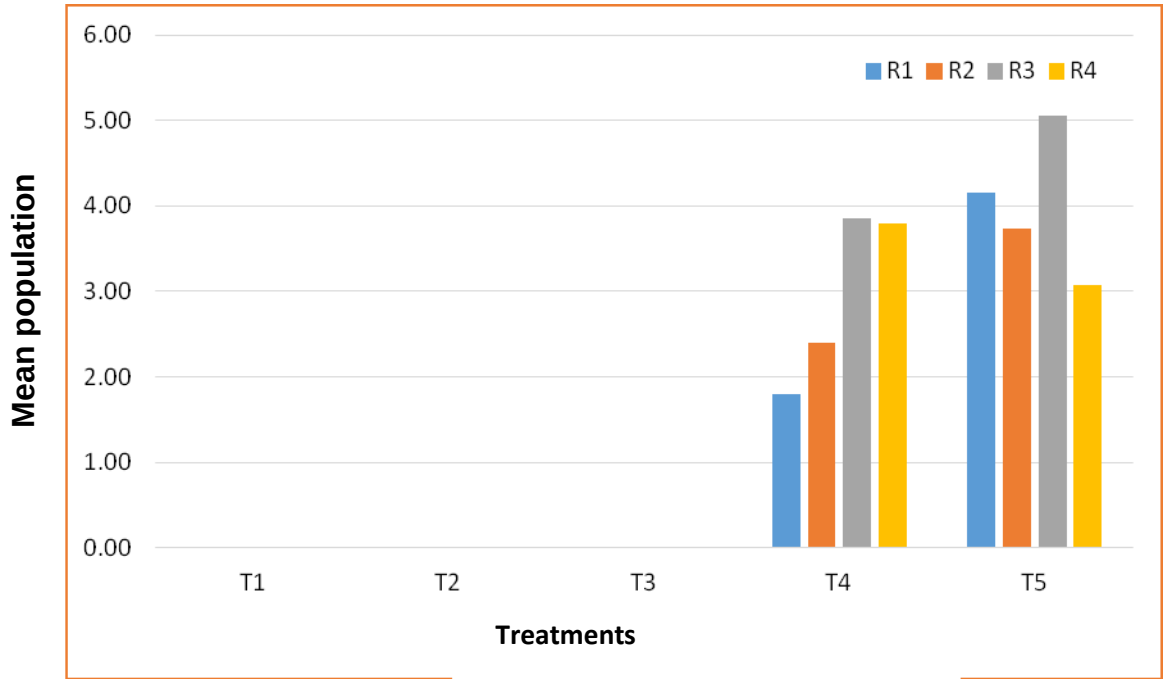

Figure 8. Population of White stink bug in various treatments