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Invasive Alien Insect Pests: A jumping threat to food security and farmers' livelihoods

B K Sreedhar, N Senthilraja, Naziya Patan and A Raja Reddy*

Al-Mussaib Technical College, Al-Furat Al-Awast Technical University, Babylon, Iraq

*E-mail: dean.agriculture@mallareddyuniversity.ac.in

Abstract

From time to time several exotic pests are invaded outside their native range into a particular area and causing potential havoc to food security and livelihoods of farmers. From the pretext, crops are constantly facing threats from many biotic stresses, particularly by invasive alien insect pests. These biological incursions cause extensive ecological damage and are quite detrimental to the major economic sectors including agriculture, horticulture, and forestry. Invasive alien pests are those that invaded the area where earlier these are not present in those areas by trade, transport or by human interference distributed to different geographic localities and colonialized successfully. Due to their polyphagous feeding habit, these non-indigenous pests cause a significant amount of damage to several food crops leaving farmers in distress besides fetching lower production and productivity. To curtail their growth and development many natural enemies viz, predators and parasitoids which are the need of the hour had been imported from their native place to control the exotic insect pests. The adoption of biological control to curb the spread of alien pests is ecologically and economically safe. However, if all the ecologically possible attempts become futile in controlling the pests, as a last resort chemical control with a different mode of action should be selected to make pest-resilient sustainable agriculture.

Keywords: Chemical control, invasive alien insects, natural enemies, parasitoids, predators.

Introduction

Over the last century, globalization accelerated rapidly which leads to an increase in tourism, transport, trade, and travel that contribute to the dissemination of pests from one place to another (Wittenberg and Cock, 2001). Due to vast expansion, and prolific reproduction ability these alien or non-native species pose a serious menace to agriculture, biological diversity, and natural ecosystems (Pimentel, 2002 and Carruthers, 2003). Agriculture is the backbone of the Indian economy where many invasive pest species show negative impacts on agriculture crop production as well as the economy (Sharma *et al*., 2018). Essentially invasive alien species comprise all classes of living organisms which are substantially dispersed in all kinds of environments but insects, plants and mammals occupy the most diversified niche, *i.e.* terrestrial ecosystem (Raghubanshi *et al.,* 2005; Sujay *et al.,* 2010). Insects which are flexible and predominantly exist in all kinds of environments, constitute about 66% of the total known species in the animal kingdom and are often regarded as successful invaders (McLaughlin and Dearden, 2019). The spread of exotic pests is now recognized as one of the greatest threats to the ecological and economic well-being of the country (Rao *et al*., 2018). In the United States, crop and forest production losses from invasive insects and pathogens have been estimated to tune US$40 billion per year (Paini *et al*., 2016). The outbreak of fall armyworm has affected maize cultivation in 122 villages of Mizoram in India and the state government has informed the Centre about an estimated crop loss of Rs 20 crore in 2019 (Anonymous, 2019). Based on 2018 projections by the Food and Agriculture Organization of the United Nations (FAO), up to 17.7 million tonnes of maize are lost annually due to FAW alone representing enough to feed tens of millions of people and an average economic loss of USD 4.6 billion globally (Anonymous, 2020). Crop losses due to papaya mealy bug can have severe economic impacts one study found that infestations of papaya orchards in Bangladesh led to an average economic loss of approximately US$700 per hectare per year (range from US$413–1268). It has been observed that farmers in India can incur a mean yield loss of up to about $13 billion of crop loss each year due to these alien insect pests (Gupta *et al*., 2008). The factors responsible for the successful invasiveness of the species relied on high fecundity, parthenogenesis, generalist feeders, rapid reproduction rate, habitat requirements, hardy growth, sustained for long period, aggressive feeding ability, ubiquitous distribution, very strong, rapid growth habit, and the ability to migrate long distances and prolific breeding potential (Cowie, 2000). The ISSG (Invasive Species Specialist Group) of IUCN (International Union for Conservation of Nature) has identified 100 of the World's Worst Invasive Alien Species, which includes plants, animals and pests.

In India, the nodal agency "Directorate of Plant Protection Quarantine and Storage" (DPPQS) is responsible for the enforcement of plant quarantine regulations under the Destructive Insect and Pest Act, of 1914. Plant Quarantine (Regulation of Import into India) Order, 2003 aims at preventing the entry, colonization and dissemination of exotic insect pests into India. In India, there are five regional plant quarantine stations at Amritsar, Kolkata, Chennai, New Delhi and Mumbai and minor plant quarantine stations functioning with 44 seaports, 23 airports and 19 land frontier stations (DPPQS, 2011). This review provides brief insights into different types of invasive alien insect pests that invaded India (Table 1), their origin and distribution, introduction sources, host crops, damage symptoms (Table 2), natural enemies preying on invasive insect pests and control of invasive pests (Table 3).

What are Alien species?

Species whose introduction or spread outside their natural habitat defined as Alien species or exotic or non-indigenous species.

What are Invasive species?

According to the International Union for Conservation of Nature and Natural Resources (IUCN) invasive insect pest is one which becomes established in natural or semi-natural ecosystems or habitats, and threatens native biological diversity.

What are Invasive alien species?

Invasive alien species can be defined as species whose introduction and/or spread threaten biological diversity.

Ideal characteristics the insect species should possess to become a successful invasive alien pest

1. The species should be introduced from outside the frontier of the country.
2. The introduced species should possess a high reproductive potential within the country.
3. The established species should result in detrimental effects on biodiversity, agro-ecosystem, commodity loss, social and health hazards.
4. The introduced species should be licenced by authorities as invasive alien species.
5. If the above characteristics are not satisfied by an insect pest then it is declared as a non-alien/non-exotic or indigenous species. (Sandilyan, 2018).

Stages of Biological invasion of invasive alien insect pests

The biological invasion of exotic insect pests occurs in a series of three phases *viz*., 1) Introduction 2) Establishment and 3) Spread.

1. Introduction

Species moving from one place and invading into the other place which were not existing earlier by different modes of transport. The introduction of exotic insects is further classified into two types viz., a) Intentional and b) Unintentional mode of introduction.

a. Intentional or deliberate introduction

The deliberate introduction of alien insects to new locations by humans for food, social or economic purposes is referred to as an intentional introduction.

b. Unintentional introduction

Contrary to the intentional introduction here exotic insects are introduced to new areas accidentally by trade, travel and transport called an unintentional introduction.

2. Establishment

The introduced species establish and reproduce successfully (*i.e.* there usually needs to be more than one individual) until they establish a self-sustaining population.

3. Spread

In certain cases, established populations will multiply rapidly and spread across the landscape. This is the explosion phase, and may only happen after a considerable lag phase (low densities of insect population) (Ali *et al*., 2020).

Table: 1 List of Invasive alien insect pests reported in India

S.No	Common name	Scientific name	Order	Family	Origin	References
1.	Apple woolly aphid	*Eriosoma lanigerum* (Hausmann)	Homoptera	Aphididae	China	Mishra (1920)
2.	San Jose scale	*Quadraspidiotus periniciousus* Comstock	Homoptera	Diaspididae	China	Singh (2004)
3.	Diamondback moth	*Plutella xylostella* (Linn.)	Lepidoptera	Plutellidae	Europe	Fletcher (1914)
4.	Lantana bug	*Ortheziz insignis* (Browne)	Homoptera	Orthezidae	Sri Lanka, West indies	Muniappan and Viraktamath, (1986)
5.	Cottony cushion scale	*Icerya purchase* (Maskell)	Homoptera	Margarodidae	Australia	Singh (2004)
6.	Potato tuber moth	*Phthorimaea operculella* (Zellar)	Lepidoptera	Gelechiidae	Italy	Singh (2004)
7.	Pine woolly aphid	*Pineus pini* (Macquart)	Homoptera	Adelgidae	Australia, Europe and New Zealand	Singh (2004)
8.	Subabul psyllid	*Heteropsylla cubana* Crawford	Homoptera	Psyllidae	Central America	Jalali and Singh (1989)
9.	Serpentine leaf miner	*Liriomyza trifoli* Burgess	Diptera	Agromyzidae	USA	Singh (2004)
10.	Coffee berry borer	*Hypothenemus hampei* Ferrari	Coleoptera	Scolytidae	Sri Lanka	Vega *et al*. (1999)
11.	Spiralling whitefly	*Aleurodicus disperses* Russell	Homoptera	Aleyrodidae	Hawaii	Palaniswami *et al*. (1995)
12.	Coconut eriophyid mite	*Aceria gurreronis* Keifer	Arachnida	Eriophyidae	Mexico	Singh (2004)
13.	Silver leaf whitefly	*Bemisia argentifolii* Bellows & Perring	Homoptera	Aleyrodidae	Greece	Singh (2004)
14.	Papaya mealybug	*Paracoccus marginatus* (Williams & Granara de Willink)	Hemiptera	Pseudococcidae	Mexico	Jhala *et al*. 2008
15.	Erythrina gall wasp	*Quadrastichus erythrinae* (Kim)	Hymenoptera	Eulophidae	Taiwan	Faizal *et al*. 2006
16.	Mealybug	*Phenococcus solenopsis* (Tinsely)	Homoptera	Pseudococcidae	Central America	Nagrare *et al*. (2009) and Ben-Dov (2004)
17.	Eucalyptus gall wasp	*Leptocybe invasa* Fisher and La Salle	Hymenoptera	Eulophidae	Australia	Nagrare *et al*. (2009)
18.	South American tomato leaf miner	*Tuta absoluta* (Meyrick)	Lepidoptera	Gelechiidae	South America	Sridhar *et al*. (2014)
19.	Coconut Rugose spiralling whitefly	*Aleurodicus rugioperculatus* (Martin)	Homoptera	Aleyrodidae	Florida	Sundararaj and Selvaraj (2017).
20.	Maize Fall armyworm	*Spodoptera frugiperda* (J.E. Smith)	Lepidoptera	Noctuidae	Tropical & Subtropical America	Shylesha *et al*. (2018); Sparks, (1979)
21.	Coconut Nesting whitefly	*Paraleyrodes minei* Iaccarino	Hemiptera	Aleyrodidae	Syria	Chandrika Mohan *et al*. (2019)
22.	Coconut Bondar's Nesting Whitefly	*Paraleyrodes bondari* Peracchi	Hemiptera	Aleyrodidae	Central America	Josephrajkumar *et al*. 2019
23.	Neo tropical coconut whitefly	*Aleurotrachelus atratus* Hempe	Hemiptera	Aleyrodidae	Brazil	Selvaraj *et al*. (2019)
24.	Tobacco thrips	*Thrips parvispinus* (Karny)	Thysanoptera	Thripidae	Indonesia	DPPQS (2022)

Table 2. List of host plants, distribution, and introduction pathway damage symptoms of Invasive alien insect pests

Common name	Host plants	Distribution in India	Mode of entry	Damage symptoms	Reference
Apple Woolly aphid	Peach, pear, almond etc	Assam, Himachal Pradesh, Punjab, Jammu & Kashmir, West Bengal, Sikkim and Uttar Pradesh	Transported by infested apple rootstocks	Infestation leads to sooty mould formation on leaves & fruits and later formation of galls on roots thus weakening the plant growth.	Gontijo *et al*., (2012), Beers *et al*. (2007)
San Jose scale	Apple, plum, peach, pear, apricot, cherries & ornamental plants	Andhra Pradesh, Assam, Punjab, Delhi, Maharashtra, Uttarakhand, West Bengal, Odisha Karnataka, Himachal Pradesh & Tamilnadu	Transported by humans and infected fruits	Purplish-red halos on young bark and leaf tissues followed by the formation of sooty mould.	Thakur *et al*. (1989), Pruti and Rao, (1951)
Cottony cushion scale	Citrus, *Acacia* sp, Strawberry, Rose, Jasmine, pomegranate Lucerne & Casurina	Andhra Pradesh, Gujarat, Tamil Nadu, Maharashtra, Madhya Pradesh, Kerala, Karnataka, Uttar Pradesh, West Bengal & Odisha	Introduced by clothing and by harvesting infested plant material	Defoliation and dieback of twigs are the typical symptoms of cottony cushion scale	Verma *et al*. (2012)
Papaya mealybug	Papaya, mango, citrus tomato, eggplant, okra beans, cotton, sweet potato, pomegranate, guava, rubber, teak, red gram, mulberry	Andhra Pradesh, Arunachal Pradesh, Jammu & Kashmir, Assam, Punjab, Maharashtra, Tamilnadu, Rajasthan, Tripura & West Bengal	Transportation of infested papaya fruits.	Symptoms include Chlorosis, plant stunting, leaf deformation and crinkling of the leaf eventually plant death will be seen.	Miller and Miller, (2002); Heu *et al*. (2007)
Coconut perianth mite/ Coconut mite	Palmyra palm, cocosoid palm, Young queen palm	Andhra Pradesh, Karnataka, Kerala, Gujarat, Odisha Maharashtra, Tamil Nadu & West Bengal.	Transportation, vector transmission, seed-borne, and infected seedlings	Triangular white patch next to the margin of the perianth; the damaged tissue turns necrotic and corklike, sometimes with deep fissures and gummy exudates. Premature nut drop followed by a reduction in nut size and copra yield.	Navia *et al*. (2012).
Serpentine leafminer	Tomato, potato, brinjal, cabbage, cotton, soybean, groundnut, okra & cucurbits	Andhra Pradesh, Gujarat, WestBengal, Madhya Pradesh, Haryana, Maharashtra, Kerala and Karnataka	Invaded through infested chrysanthemum cuttings.	The larvae eat the mesophyll of leaflets leaving long winding tunnels inside the leaflets.	Mujica *et al*. (2016)
Potato tuber moth	Potato, tomato and tobacco	Assam, Bihar, West Bengal, Odisha, U.P, Himachal Pradesh, Karnataka, Tamil Nadu, Maharashtra & Gujarat	Transported through bulbs, tubers, corms and rhizomes.	Larvae mine leaves, stems, and petioles, and excavate tunnels through potato tubers which are considered the typical damage.	Alvarez *et al*. (2005)
(Diamondback moth	Crucifers and *Amaranthus viridis*	Punjab, Haryana, Himachal Pradesh, Delhi, Uttar Pradesh, Bihar, Tamil Nadu, Maharashtra and Karnataka.	Dispersed through seedling transplants, crop residues and	Larvae of DBM damage the leaves by making small holes on the surface of leaves, often leaving the epidermis of leaves which is called the Feeding Window.	Furlong *et al*. (2013)

Common name	Host plants	Distribution in India	Mode of entry	Damage symptoms	Reference
Coffee berry borer	*Coffee arabica* (arabica) and *Coffee canephora* (robusta)	Karnataka, Kerala & Tamil Nadu	Introduced through seeds brought by refugees or through illegally imported coffee seeds	The white, grubs feed by tunnelling leaving one or more small round holes near the apex of large green or ripe berries.	Vega *et al*. (2009), Anonymous, (2003)
Spiralling whitefly	Banana, papaya guava, avocado, coconut, dahlia, cucurbits, gerbera, gladiolus, tomato, mulberry, tapioca	Karnataka, Andhra Pradesh, Maharasthra, Tamil Nadu, Orissa and North East region.	Trade and transportation of infected leaves & fruits	Adults and nymphs of the whitefly cause damage by direct feeding on plant sap followed by honeydew excretion which inhibits plant growth.	Srinivasa, (2000), Geetha and Swamiappan, (2001)
Cotton mealybug	Okra, brinjal, chilli, tomato, guava, grapes pomegranate and china aster	Punjab, Haryana, Rajasthan, Madhya Pradesh, Karnataka Maharashtra, Andhra Pradesh, Tamil Nadu and Gujarat	Transported through air, seas etc	Nymphs and adults congregate on the lower surface and suck the sap subsequently producing honeydew	Nagrare *et al*. (2009), Vennila *et al.* (2010)
Tomato pinworm	Tomato, brinjal, potato, pepper, Datura	Karnataka, Andhra Pradesh Telangana, Gujarat, Maharashtra and Tamilnadu	Tomato trade and, to a lesser degree, active flight or passive movement on wind currents	The larvae fed on mesophyll tissues and made irregular mines or created blotches on the leaf surface and the mines were visible from both sides of the leaf.	Kalleshwaraswamy *et al*. (2015), Ballal *et al.* (2016)
Fall armyworm	Maize, rice, sorghum, sugarcane, cabbage, beet, peanut, soybean, alfalfa, onion, tomato, potato and cotton	Karnataka, Tamil Nadu, Andhra Pradesh, Telangana and Maharashtra	Invaded by mass swarming	Epidermal leaf tissues are mostly preferred by young larvae and make holes in leaves, which is the peculiar damage symptom of FAW.	Sharanabasappa *et. al.* (2018)
Rugose spiralling whitefly	Banana, coconut, guava, mango, bhendi, papaya, sapota, citrus custard apple	Tamil Nadu, Karnataka, Kerala, Andhra Pradesh, Maharasthra, Odisha and Lakshadweep	Unknown	The excretion of sooty mould on leaves prevents the process of photosynthesis leading to physiological disorders.	Selvaraj *et al.* (2016), Francis *et al*. (2016)
Subabul Psyllid	*Leucaena*, mimosa, monkey pod, *Albizia saman*	Tamil Nadu, Karnataka and Andhra Pradesh	Transported through aircraft, insects being attracted to aircraft or airport lights	Psyllids suck plant juices and excrete sticky honeydew on which thick blackish mould grows. High psyllid populations reduce plant growth or cause terminals to distort, discolour, gall, or die back.	Burkhardt (1986), Muddiman *et al*. (1992)
Eucalyptus gall wasp	*Eucalyptus camaldulensis*; *Eucalyptus tereticornis*; *Eucalyptus grandis*; *Eucalyptus deanei* etc	Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Gujarat, Maharashtra and Madhya Pradesh	Exchange of infected seedlings	Infestation leads to the formation of galls on shoots, stems petioles and midribs.	Gupta *et al*. (2019)

Common name	Host plants	Distribution in India	Mode of entry	Damage symptoms	Reference
Silver leaf whitefly	*Poinsettias*, *Pelargonium*, *Impatiens*, *Gerbera* sp, *Hibiscus* sp, *Begonia* sp., *Gossypium* sp.	Gujarat, Karnataka and Maharashtra	Transportation, agricultural practices with infected material	There are four kinds of symptoms including a) Non-uniform ripening of tomato fruits, b) sooty mould c) transmission of tomato yellow leaf curl virus d) cosmetic damage by adults & nymphs.	Gupta *et al*. (2008), Reddy *et al*. (2006)
Pine woolly aphid	*Pinus canariensis*, *Pinus caribaea*, *Pinus contorta, Pinus halepensis*	Not reported	Longer distance spread is via the movement of infested nursery stock	Infestation causes premature needle shedding and reduction in the length of infested needles discolouration of foliage, distortion, resinosis, death of branches and death of trees	McClure, (1989)
Erythrina gall wasp	*Erythrina variegata*, *Erythrina fusca, Erythrina indica*	Karnataka, Maharashtra, West Bengal and Kerala	Ships, clothing and wind	The female wasp makes galls on vegetative parts *viz*., leaves, shoots, petioles and inflorescences of the plant	Heu *et al*. (2008), Howard *et al*. (2008)
Lantana bug	*Lantana*, *Clerodendron*, *Duranta* sp, *Capsicum Eupatorium Coffee*, *Casurina*, *Jacaranda*, *Chrysanthemum* spp.	Karnataka, Kerala, Maharashtra, Tamil Nadu, and West Bengal	Through imported plants	Scale insect damage the host plant by feeding on its phloem and excreting the nutrients which promote the growth of sooty mould.	Ben-Dov *et al*. (2006),
Coconut nesting whitefly	Citrus, coconut, mango, Jamun, banyan, teak, Indian almond	Andaman and Nicobar Islands, Karnataka, Kerala and Tamilnadu	Unknown	It is commonly known as a “nesting whitefly” due to its characteristic pattern of laying eggs in a white “nest” of woolly wax secreted by the females. The whitefly starts attacking from the lower leaves and drains the sap from the underside of the leaves, producing honeydew and leading to the growth of black sooty mould.	Sujithra *et al.* (2019); Anonymous, (2019).
Coconut bondars nesting whitefly	Banana, avocado, citrus, cassava, custard apple, ornamental *Ficus spp*.	Andaman and Nicobar Islands, Karnataka and Kerala	Unknown	Excessive de-sapping by the pest produces honeydew which results in sooty mould deposits on the plant surface.	Chandrika Mohan *et al*. (2019)
Neo tropical whitefly	Citrus, brinjal, coconut, and areca palm	Karnataka	Unknown	The upper surfaces of infested palm fronds often exhibit chlorosis and necrosis. Large whitefly infestations may cause wilting and the plant may lose vigour;	Selvaraj *et al*. (2019), Annonymous. (2020)
Tobacco thrips	Beans, eggplant, papaya, pepper, potato, shallot, strawberry, Chill, and ornamental crops	Andhra Pradesh, Chhattisgarh, Karnataka, Kerala, Gujarat, and Tamil Nadu	Unknown	Colonize on flowers and the underside of leaves whereas larvae suck sap from the undersurface of the leaves. Infestation causes heavy flower drops and reduces fruit production.	DPPQS (2022)

Despite sophisticated technological development, insect pests often continue to express high pressure on agriculture and human health. To curtail the menace caused by these exotic pests use of natural enemies otherwise called biological control agents was found to be an established and commercially successful approach (Hajek, 2004). Biological control offers a self-sustaining solution for the suppression of invasive insect pests (Table 3). To achieve sustainable biological control; traditionally there are three different types of biological control strategies employed in pest control programs. These are Importation, Augmentation and Conservation. Importation or Classical biological control (CBC) is defined as the importation of natural enemies from the native origin of a pest to attain permanent control of the pest (Van Driesche *et al*. 2010). On the other hand, augmentation typically involves the release of natural enemies or environmental manipulation to enhance the effectiveness of natural enemies by the supplemental release of natural enemies, at a critical time of the season called inoculative release or release of a large number of natural enemies periodically called inundative release. The third important strategy is Conservation, which can be successfully achieved by vegetative manipulation. Common natural enemies include predatory insects *viz*, lacewings, ladybugs, and preying mantids. While a parasitoid is categorized according to the life stage of the host that they attack *viz;* Egg Parasitoids: Egg parasitoids kill their hosts before they hatch, thus preventing crop damage by emerging larvae. Egg Larval Parasitoids are species that initially parasitize the egg, and categorically complete their metamorphosis in a later development stage *i.e*. Larva; Larval Parasitoids: Larval parasitoids kill their hosts before they hatch into pupae *i.e* attacking in larval stage thus preventing from emerging into a pupa. Pupal Parasitoids: Attacks during the pupal stage and halts the pupal development from emerging into adults Nymphal Adult Parasitoids: are species that initially parasitize the nymphs, and complete their metamorphosis in an adult stage *i.e.* Adult (Wright, 2014).

Table 3. List of the Natural enemies (Predators and Parasitoids) reported against Invasive alien insect pests

S. No.	Invasive alien insect	Predators	Parasitoids	References
1.	Apple woolly aphid	Syrphids- *Heringia calacarata* Loew, *Eupeodes americanus* Thomson Coccinellids-*Coccinella transversoguttata* Brown *Hippodamia convergens* Guérin-Méneville Chrysopid- *Chrysopa nigriconi* Burmeister Earwig- *Forficula auricularia* Linnaeus	NA Parasitoid: *Aphelinus mali* Haldeman	Gresham *et al*. (2013), Gontijo *et al*. (2012)
2.	San Jose scale	Coccinellids- *Coccinella inferalis*	NAP: *Encarsia perniciosi* Tower ELP: *Aphytis aonidiae*, Merect ELP: *Aphytis vandenboschi* De Bach & Rosen	Daane (2002).
3.	Cottony cushion scale	Vedalia beetle - *Radolia cardinalis*, Mulsant, Parasitic fly- *Cryptocheatum iceryae* Williston	No parasitization is reported	Cardwell, (2002)
4.	Diamondback moth	Coccinellids- *Coleomegilla maculate* DeGeer *Hippodamia convergens* Guérin-Méneville Syrphids- *Toxomerus dispa*, Fabricius Chrysopids-*Ceraeochrysa claveri* Navás	EP: *Trichogramma brasiliensis*, Ashmead LP: *Apanteles plutellae* Kurdjumov PP *Spilochalcis hirtifemora* Ashmead	Alam, (1974), Yaseen, (1978)
5.	Potato tuber moth	Coccinellids- *Brumoides suturalis*, Fabricius Chrysopids- *Chrysoperla carnea*, Stephens Bigeyed bugs: *Geocoris tricolor*, Fabricius *Orius lavigaetus* Fieber	LP: *Copidosoma koehleri* Blanchard LP: *Bracon gelechiae* Ashmead.	Alvarez *et al*. (2005)

S. No.	Invasive alien insect	Predators	Parasitoids	References
6.	Papaya mealy bug	Coccinellids: *Cryptolaemus montrouzieri*, Mulsant Apefly: *Spalgis epius* Westwood	LP: *Acerophagus papayae*, Noyes & Schauff *Anagyrus loecki*, Noyes and Menazes *Pseudleptomastix Mexicana* Noyes and Schauff	Muniappan *et al*. (2009), Venkatesha *et al*. (2011)
7.	Cotton mealybug	Coccinellids: *Cryptolaemus montrouzieri*, Mulsant *Cheilomones sexmaculata*, Fabricius Chrysopids: *Chrysoperla carnea*, Stephens Apefly: *Spalgis epius* Westwood	LP: *Aenasius bambawalei* Hayat	Nagrare *et al*. (2011)
8.	Spiralling whitefly	Coccinellids- *Anegleis cardoni*, (Weise) *Cryptolaemus montrouzieri*, Mulsant Chrysopids- *Mallada boninensi*, Okamoto *Chrysoperla carnea* Stephens	NA Parasitoid: *Encarsia guadeloupae* Viggiani	Mani and Krishnamoorthy, (1999)
9.	Coffee berry borer	Thrips- *Karnyothrips flavipes* Jones	LP: *Prorops nasuta*, Waterston LP: *Cephalonomia stephanoderis*, Betrem LP: *Phymastichus coffea* Lasalle	Jaramillo (2008), Chapman *et al*. (2009)
10.	Serpentine leaf miner	Mirids- *Cyrtopeltis modestus*, Distant *Dicyphus tamaninii*, Wagner *Macrolophus caliginosus* Wagne	PP: *Diglyphus begini* Ashmead PP: *Hemiptarsenus varicornis* Girault	Sujay *et al*. (2010)
11.	South American tomato moth	Mirid bug- *Nesidiocoris tenuis* Reuter	EP: *Trichogramma achaeae*, Nagaraja and Nagarkatti PP: *Neochrysocharis Formosa*, Westwood EL: *Habrobracon* sp. LP: *Goniozus* sp	Luna *et al*. (2011), Ballal *et al*. (2011)
12.	Rugose Spiralling whitefly	Chrysopid - *Mallada* spp.	NA: *Encarsia guadeloupae* Viggiani	Selvaraj *et al*. (2016)
13.	Fall armyworm	Coccinellids- *Harmonia octomaculata*, Fabricius *Coccinella transversalis*, Fabricius Earwig- *Forficula* sp.	LP: *Coccygidium melleum*, Roman LP: *Campoletis, chlorideae*, Uchida EP: *Trichogramma pretiosum* Riley LP: *Eriborus* sp. LP: *Odontepyris* sp LP: *Exorista sorbillans* Wiedmann	Sharanabasappa *et al*. (2019)
14.	Coconut eriophyid -mite	Ascid mites/Phytoseiidae mites: *Lasioseius* sp, *Proctolaelaps* sp, *Proctolaelaps bickleyi*, *Amblyseius largoensis*, *Neoseiulus baraki*, *Neoseiulus mumai, Neoseiulus paspalivorus*	So far no parasitoids have been reported parasitizing coconut mites	Navia *et al*. (2012)
15.	Subabul psyllid	Coccinellids *Curinus coeruleus*, (Mulsant *Olla obdominalis*, Say) *Menochilus sexmaculatus*, Fabricius Syrphid fly: *Ischiodon scutellaris* Sack	LP: *Psyllaephagus sp. nr. Rotundiformis* Howard	Jalali and Singh, (1989)

S. No.	Invasive alien insect	Predators	Parasitoids	References
16.	Silver leaf whitefly	Phytoseiidae mites- *Amblyseius limonicus* Garman & McGregor Chrysopids: *Chrysoperla carnea* Stephens	NA Parasitoid: *Encarsia* sp., NA Parasitoid: *Eretmocerus* sp.	CABI, (2020)
17.	Pine woolly aphid	Dipteran fly: *Leucopis tapiae*, Greathead Coccinellids: *Diomus pumilio*, Weise *Exochomus quadripustulatus* Linnaeus	So far no parasitoid has been reported parasitizing pine woolly aphids.	FAO, (2013)
18.	Eucalyptus gall wasp	No predators has been reported	LP: *Quadrastichus mendeli*, Kim & La Salle PP: *Megastigmusdharwadicus* Narendran & Vastrad LP: *Aprostocetus gala*, *Aprostocetus causalis* La Salle & Wu	Shylesha, (2012), Narendran *et al*. (2010)
19.	Erythrina gall wasp	No predator had been reported preying on Erythrina gall wasp.	LP: *Aprostocetus exertus* La Salle LP: *Eurytoma erythrinae* Gates and Delvare	Salle *et al*. (2009)
20.	Lantana bug	Coccinellids: *Hyperaspis pantherine* Fursch	Not reported	Fowler, (2003)
21.	Coconut nesting whitefly	Coccinellids*, Clitostetus arcuatus* (Rossi) and *Serangium parcesetosum* Sicari	NA: *Encarsia dominicana* Evans, *E. sp. gr. parvella* Silvestri or *E. variegata* Howard	Sujithra *et al*. (2019)
22.	Coconut bondars nesting whitefly	No predators has been reported	No parasitoids have been reported	Josephrajkumar *et al*. (2019)
23.	Neo tropical whitefly	Chrysopid- *Dichochrysa astur* Banks Coccinellids- *Cybochephalus* spp.: *Chilocorus nigrita* Fabricius and *Jauravia pallidula* Motschulsky	NA: *Encarsia basicincta* Gahan and *Eretmocerus cocois* Curtis	Selvaraj *et al*. (2019)
24.	Tobacco thrips	Not reported	Not reported	-

EP = Egg Parasitoid EL = Egg Larval Parasitoid LP = Larval Parasitoid PP = Pupal Parasitoid NA = Nymphal & Adult Parasitoid

In Integrated pest management, control of insect pests by synthetic insecticides could be practised only as a last resort with a concern for natural enemies, pollinators and the environment which shows detrimental effects (McLaughlin and Dearden, 2019). Chemical controls, particularly synthetic organic insecticides, have been developed for almost every insect pest (Table 4). The wide acceptance of synthetic chemicals is due to their highly effective nature, one product often controls several different pests; there is a relatively low cost for product or labour; and generally, their effects are predictable and reliable. Chemical insecticides have allowed the management of larger acreages by fewer individuals because of the reduced labour needed for physical and mechanical controls. To protect our crops from losses due to insect pests and to increase the benefits for farmers, insecticides are being used as a major control tactic. (Rathee *et al*., 2018). Insecticides are agents or tools of chemical or biological origin that manage or control insects significantly; control may result from killing the insect or otherwise preventing it from engaging in behaviours believed to be destructive. The insecticides may be applied in a myriad of formulations (EC, WP, WDG, OD, SL, D, G) *etc*. Insecticides act on the target pest in various ways by targeting either a specific system or may affect the broad spectrum that prevents the development of insecticide resistance (Ghosal *et al*., 2018).

Table 4. Chemical control of Invasive alien insect pests

S. No.	Common name	Chemical control	Reference
1.	Apple woolly aphid	A spray of phosphamidon 40 SL @ 0.5 ml/lit, chlorpyrifos 20 EC @ 2.5ml, and fenvalerate 20EC @ 0.1 ml/lit. For root infestation, application of carbofuran 3 % G @70-100 gm by hoeing the 5 cm soil in depth around the tree trunk.	Gupta *et al*. (2015)
2.	San Jose scale	Chlorpyriphos 20 EC @ 2.5 ml/lit, dimethoate 30 EC @ 1 ml/lit, pyriproxyfen 0.07%, phenoxycarb 0.05 % and mineral oil 1.0% can significantly reduce the scale infestation.	Shaw *et al.* (2000), Sazo *et al*. (2008)
3.	Diamondback moth	Spraying of Emamectin benzoate 5 SG @0.005 % cyantraniliprole 10.26 OD @0.08 % spinosad 45 SC @0.01 % and Fenvalerate 20 EC @0.04 % was found to be effective.	Gautam *et al*. (2018)
4.	Lantana bug	Sprays containing soaps are more effective. Insecticides *viz*, imidacloprid and thiamethoxam @1g/L are applied to the foliage.	Green, (1922)
5.	Cottony cushion scale	Spraying of pyriproxyfen 10 EC @ 1 ml/lit is as effective in controlling gave 100% mortality of crawlers.	Gokkes *et al*. (1989) Mendel *et al*. (1991)
6.	Potato tuber moth	Initially, chloranrhaniliprole 18.50 SC, chlorpyrifos ethyl 50 + cypermethrin 5EC, deltamethrin and Indoxcarb 14.50 SC show the strongest effect on the young larva of potato tuber moth followed by Indoxacarb 15% EC, lufenuron 5% EC and methoxyfenozide 24% SC sprayed at 15 days intervals.	Gancheva and Dimitrov, (2013)
7.	Pine woolly aphid	Abamectin, Spirotetramet, Pyriproxyfen, Chlorpyrifos, and Dimethoate have been recommended.	Bush, (2019)
8.	Subabul psyllid	Spraying of dimethoate 30 EC @ 0.05% 1 ml/litre was found effective against subabul psyllid.	Rajagopal *et al.* (1990)
9.	Serpentine leaf miner	profenophos40% + cypermethrin 4% @ 0.6 ml/lit of water was widely used against leaf-mining larvae.	Rai *et al*. (2017), Civelek and Weintraub, (2003)
10.	Coffee berry borer	Cyantraniliprole 100 OD and chlorantraniliprole 8.8 % + thiamethoxam 17.5 % EC are found to be effective.	Souza *et al*. (2013), Arcila *et al*. (2013)
11.	Spiralling whitefly	Malathion @ 0.1%, dichlorvos @ 0.08%, triazophos @ 0.08% and dimethoate @ 0.05% with insecticidal soap at 2.5% were found to be effective in suppressing the nymphal and adult whitefly population.	Ragumoorthy and Kempraj, (1996), Reddy (2015)
12.	The coconut eriophyid mite	Application of monocrotophos 36% SL 0.05%, lambda-cyhalothrin 50% EC 0.005%, sulphur 80% WW 0.3%, phosalone 35 EC 0.07%, thiamethoxam 25% WG 0.006% are found effective. Root feeding with Fenazaquin IOEC @10 ml/ plant was found effective.	Yuvaraja (2004), Dey *et al*. (2001)
13.	Silver leaf whitefly	A spray of Imidacloprid 200 SC @ 5g a.i/100 m row length was found to be effective.	De Barro *et al*. (2006)
14.	Papaya mealybug	Spray of profenophos 50 EC @ 2ml/lit, chlorpyriphos 20 EC @ 2ml/lit, buprofezin 25 EC @ 2ml/lit, and dimethoate 30 EC @ 2ml/lit of water were found effective.	Thangamalar *et al*. (2010)
15.	Erythrina gall wasp	Stem injection with Emamectin benzoate @ 0.1 a.i/cm diameters and imidacloprid @ 0.16 a.i/cm diametre were found to be effective.	Doccola *et al*. (2009)
16.	Cotton mealybug	Profenofos50 EC @ 0.1% chlorpyrifos 20 EC @ 0.4%, obtained better results	Jhala *et al*. (2010)
17.	Eucalyptus gall wasp	Application of carbofuran 3G @ 0.5 or 1.0 g and imidacloprid 17.8 SL @ 0.25 ml/litre per plant was found effective.	Aregowda *et al*. (2010)

S. No.	Common name	Chemical control	Reference
18.	South American tomato leaf miner	Application of profenophos 40% + cypermethrin 4% EC @ 0.5 ml/lit followed by dimethoate 50 EC @ 2 ml/lit and Imidacloprid 600 FS @ 0.5ml/lit of water found to be effective.	Rai *et al*. (2017), Abdelgaleil *et al*. (2015)
19.	Rugose spiralling whitefly	Application of 1 % starch solution on leaflets to flake out the sooty moulds followed by spraying of dinotefuran 20 SG @ 0.93 gm, Pymetrozine 50 WG @ 0.85 gm and thiamethoxam 25 WG @0.84 gm can effectively suppress the whitefly population.	Mannion (2010)
20.	Fall armyworm	Spraying of chlorantraniliprole 18.5 SC @ 0.4 ml, spinetoram 11.7 SC @ 0.5 ml thiamethoxam 12.6 % + lambda-cyhalothrin 9.5 % ZC @ 0.25 ml/lit of water was found effective at field conditions.	Deshmukh *et al.* (2020)
21.	Nesting whitefly	Currently, there are no chemical management strategies advocated to contain the pest, only biocontrol agents are practised to suppress the pest.	-
22.	Bondars Nesting whitefly	-do-	-
23.	Neo tropical whitefly	-do-	-
24.	Tobacco thrips	Need-based application of CIB & RC approved registered Insecticides for thrips in Chilli	DPPQS (2022)

Conclusion

Due to increased globalisation food crops are more vulnerable to transboundary pests which showas a significant negative impact on food security and livelihoods of farmers. Due to their polyphagous feeding habit each pest colonized many food crops and established as a key pest. These transboundary pests cross their original horizons by means of trade and transport through infested planting material and by other agencies. To prevent their entry in to an area strict quarantine regulatory measures should be deployed and it is a primary approach in containing these exotic pests. For sustainable control of these Invasive alien insect pests natural enemies *viz*, predators and parasitoids plays a pivotal role in suppressing the pest species which serves as environmentally and economically sound approach. However, some times biologically control attempts could become futile due to multiple reasons. In that, Circumstances most of the farmers embrace chemical control is a feasible approach and consider it as a silver bullet technology in suppressing the development of insect pests despite their inherent toxic properties to natural enemies. In a nutshell, management of the Invasive alien insect pests to safeguard the agriculture and farmers livelihood is of paramount importance. Hence, stringent quarantine measures, awarness campaign, use of natural enemies for sustainable control and rational use of synthetic chemicals should be practiced in order to make pest resilient sustainable agriculture.

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Mega-field demonstration of management of pink bollworm, *Pectinophora gossypiella* in rain-fed cotton using mating disruption technology

C D Mayee[1,2*], B Chaudhary[2], R Panchbhai [1], A R Annepu[3] and R D Kapur[3]

[1]Agrovision Foundation, Nagpur
[2]South Asia Biotechnology Center, Jodhpur-New Delhi
[3]PI Industries, Gurugram, Haryana
E mail: mayeecharu@gmail.com

Abstract

With large scale outbreak of pink bollworm, Pectinophora gossypiella *on cotton since last four years, the benefits of Bt cotton in terms of saving the chemical usage are waning. There are reports of resistance break down of cry toxins as also of some insecticides on multiple Bt cotton hybrids which occupy nearly 95% of the total cotton area. Efforts to educate the farmers through mass communication techniques on do's and don'ts have only partially been beneficial as the use of insecticides become the part of package of management. Therefore, non-chemical approach of mating disruption technology was demonstrated in the present study as an area-wide approach in cotton fields of farmers. A mega demonstration, called 'Project Bandhan', on 300 acres in five cluster of 60 acres each in three villages of Nagpur district of Maharashtra was organized during the rainy season of 2021-22. The mega-demo was carried out using the latest pheromone based PBKNOT dispensers supplied by PI Industries Ltd., Gurugram, Haryana. The PBKNOT dispenser was tied on to main stem at 45-50 days after planting. The results revealed that PBKNOT tied fields reduced the flower damage by 49.2%, boll damage by 58.3% and locule damage by 51.8% averaged over 300 acres of treated clusters. At the end of 10th week, the active ingredient of PBKNOT was still active as more than 93% mating disruption was visible indicating the slow release of pheromone even after three months. The average yield increase based on 300 acres was to the tune of 550 kg/ha. Being a large-scale demonstration, it appears that the technology is good option for the rain-fed cotton farmers to reduce the use of chemicals for management of pink bollworm in group farming system.*

Keywords: Bt cotton, mega demonstration, *Pectinophora gossypiella*, pink bollworm, PBKNOT dispenser, PBW-Management.

Introduction

Pink bollworm (*Pectinophora gossypiella*) has emerged as a dreaded pest of cotton in recent years. The unprecedented outbreak of the pest has hit hard the cotton farmers in Maharashtra first time in rainy season of 2017-18. There after it has appeared with differential intensity in the last four seasons throughout cotton growing states. Initial panic reaction of cotton farmers to the attack was tamed by regularly educating the farmers about do's and don'ts by Government's extension agencies, scientists from Agriculture University and Cotton Institute. In Vidarbha, Agrovision Foundation and SABC jointly organized the massive awareness campaign using the latest techniques of technology transfer like village posters, large hoardings, radio jingles, TV dialogues, campaign floats and newspaper publicity and educating the farmers through seminars-webinars in Krishi Vigyan Kendra (Mayee *et al.,*2019). The campaign was regularly organized in all cotton growing districts from 2018 to 2021 during August and September months when the PBW incidence commences. A similar pan-India project called *Project SAFAL* for awareness about the management of the newly introduced pest; fall armyworm in maize through digital and conventional networking paid rich dividends towards crop sustainability (Mayee *et al*., 2021). Since the management tips for PBW included the application of certain pesticides, the benefits of reducing the chemical use by adoption of Bt technology in cotton were waning and hence there was demand for non-chemical method for management of PBW. Specialized Pheromone and Lure Application Technology (SPLAT), a wax-based formulation having sustained release pheromone tool has given some success in area-wide management of pink bollworm of cotton (Sreenivas *et al*., 2021). Similarly, in Gujrat successful management of pink bollworms was observed in series of experiments using PB Rope L (Desai *et al*., 2022). Fortunately, a better version of the cutting-edge mating disruption technology in the form of 'PBKNOT' (supplied by P.I. Industries Ltd., Gurugram) experimented at university farm of VNMAU, Parbhani on small scale as PB Rope L gave encouraging results (Anonymous, 2018) which prompted us to take up mega-project called" PROJECT BANDHAN" in farmers' field. This paper describes the outcome of this project.

Materials and methods

Selection of farms and farmers

To get a large contiguous cotton planting area, survey was carried out in three villages where after Gram Sabha meetings in April-May 2021 the farmers agreed to participate in the project. Five clusters of 60 acres each (total 300 acres) were chosen for the mega demonstration of mating disruption using the PBKNOT technology. The details of the clusters, number of farmer participants are given in Table 1. They were all growing cotton traditionally under rainfed conditions as facilities of irrigation are not available. Every participant farmer was supplied two hybrid Bt cotton seed bags for one acre as incentive but they were free to use the other cotton area with any other hybrid Bt cotton.

Table 1: Cotton Cluster Chosen for Mega-Demo of Mating Disruption Technology in Nagpur District of Maharashtra

Name of Village	Cluster Nos.	Total Acres	Number of Farmers Participated
Waroda	I	63(09)	30
Waroda	II	66(11)	13
Adasa	III	47(14)	16
Adasa	IV	78(07)	15
Methpanjara	V	46(09)	04
Total		300(40)	78

Each Cluster of approx.60 Acres for Treatment and 10 Acres of Control (in brackets)

Application of PBKNOTS

Since the entire cotton area was under rain fed conditions, sowing of cotton were done on the onset of monsoon rains which was completed between 14 to 18 June 2021 in all the five clusters. Each cluster of 60 acres to be treated with PBROBE for management was PBW had 10 acres of control plots nearly 1000 m away from the contiguous 60- acre cluster. Recommended cultural practices were adopted such as, timely weeding, fertilizer application, management of sucking pests using neem extract and chemicals whenever the ETL of the pest crossed. However, the clusters under treatment were not allowed any chemical sprays. In treated plots, PBROBE dispensers were tied (locally called BANDHAN) on the central shoot on cotton plants at pin square stage approximately between 45-50 days after sowing. The entire border row plants plus the 7th plant in each row vertically and horizontally were tied with the PBKNOT dispenser (Fig. 1). For one cluster of 60 acres 9600 PBKNOTS were used which comes to about 160 robes per acre. The 10-acre untreated plots of each cluster were allowed use control practices for PBW as per the Government recommendations. For management of pink bollworm, the farmers used the recommended insecticides like Profenphos 50% E (2000ml/ha), Lamda Cyhalothrin 5% EC (1000ml/ha), Chlorantraniliprole 18.5% SC (200ml/ha) and/or Emamectin benzoate 5% SG (200g/ha). PBW-specific pheromone traps were installed at the rate of 5 traps per acre for monitoring the bollworm moth population both in treated and untreated plots. The lures in the traps were changed every 15 days till the moth traps were negligible.

Observations

Each cluster of 60 acres, for the sake observations, was divided into 30 equal quadrats. Observations were recorded from randomly selected ten plants in each quadrat at weekly interval. The data of all the 30 quadrats were pooled and averaged as the mean of the 60 acre cluster. The same way the 5 acre control plots were also divided in to two quadrats and the data were averaged for the control plots of each cluster. The following observations were recorded:

a) Flower damage, locule damage and green boll damage data for each cluster for treated and untreated plots were averaged as representative of the cluster.

b) The average male moth counts in the traps installed in treated and untreated plots were taken into consideration at weekly interval throughout the crop season till third flush of bolls appeared on the plants. For each cluster the percent mating disruption was calculated by dividing the catches in treated plots by the catches in control plots, multiplied by 100. The results were then pooled for the entire 300 acres of treated area and 30 acres of untreated control plots of all the three villages.

c) The farmers were allowed to harvest the cotton as per their convenience in all the clusters except that they have to weigh the produce of their plots before the representative of the project. Since each cluster of 60 acres comprised of many farmers harvesting occurred at different times. However, the yield data at each picking was recorded of the participating farmer and the data were pooled for the entire cluster of treated and untreated plots separately. Being the mega demonstration, as against the research plot practice of converting plot yield into per ha, in this case the total seed cotton yield of each cluster of 60 acres was converted to per hectare yield based on all the picking data.

Results and discussion

Efficacy of PBKNOT against pink bollworm

Results on the evaluation of the PBKNOT tied to cotton plants in all the clusters revealed that overall incidence of pink bollworm in terms of flower damage and also the green boll damage was extremely low in all the clusters (7.14 to 11.43% and 4.00 t0 6.57%, respectively) where the treatment was executed as against 7.71 to 12.29% flower damage and 20.0 t0 65.0% green boll damage in the respective nontreated fields (Tables 2). The mean reduction flower and boll damages was to the tune of 51% and 59%, respectively. Similarly, the locule damage which is one of the effects of pink bollworm incidence, was found to be minimum (9.46 to 15.18%) in treated clusters as against 21.61 to 29.64% locule damage in untreated control fields in spite of having given 4-5 rounds of insecticidal sprays exclusively to manage the pink bollworm.

Table 2: Flower, Green boll and Locule damage as influenced by PBKNOT treatment in all the clusters

Cluster No.	% Flower damage			% Green Boll damage			% Locule damage		
	PBKNOT Treated Plot	Control Plot	% of Reduction	PBKNOT Treated Plot	Control Plot	% of Reduction	PBKNOT Treated Plot	Control Plot	% of Reduction
I	4.71	7.71	61	11.43	21.43	53	10.18	21.61	47
II	4.43	8.57	52	10.18	22.86	45	9.46	25.18	38
III	4.00	9.29	43	7.14	20.00	36	12.32	26.43	47
IV	4.71	10.18	46	8.57	23.57	36	15.18	29.64	51
V	6.57	12.29	54	9.64	24.82	39	14.11	24.29	58
Average	4.88	9.61	51%	9.39	22.54	42%	12.25	25.43	49%

PBKNOT being a mating disruption technology it was important to find out how much mating disruption could occur due to the technology on 300 acres farmer fields. The probes mimicking the female by releasing the male attracting pheromone, the male moths were trapped in the specialized traps fixed in all the clusters. As a result, moths caught per trap per week were calculated and the data are shown in Fig 1.

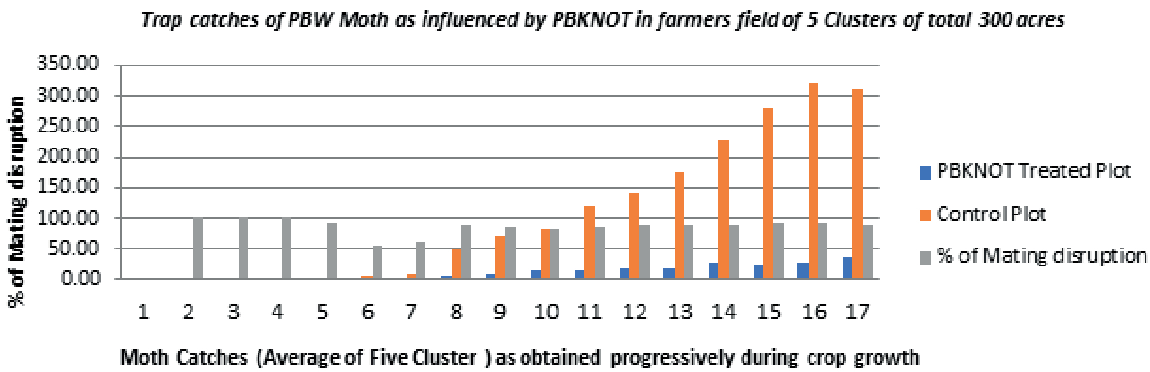

Figure 1. Trap catches of PBW moth as influenced by PBKNOT application during the cotton season

In all the clusters heavy catches were obtained in treated fields as against minimum catches in control fields. The mean percent mating disruption computed from the data of catches in treated and control fields indicated 86.3 to 88.1% disruption with an average of 87.3% mating disruption achieved due to the PBROBE treatment. Lower incidence of pink bollworm, less field damage due the pest resulted in higher yields in all the clusters (Table 3). Highest seed cotton yield of 1583 kg per ha was obtained in cluster III in treated fields as against 913 kg/ha in untreated control field. The data in Table 3 further revealed that the average cotton yield based on 300 acres improved by 550 kg/ha (408 to 742 kg/ha) due to mating disruption technology. As per the prevailing prices of the season Rs 9900 per q, the project farmers obtained additional monetary benefit of nearly Rs. 54,450 per ha using the technology. The ecological and environmental benefits further overweigh the advantages of such technologies as they are ecofriendly.

Mating disruption technology has been widely tried as a tool in management of lepidopteran pests of many crops with some success (Kong *et al.*, 2014; Miller and Gut, 2015). Cadre and Minks (1995) reviewed the successes and constraints of mating disruption technology and concluded that as an ecofriendly technology it fits well in to IPM practices. Mating disruption of Lepidopteran pests has been an important component of integrated pest management; however, commercial exploitation of the techniques needs further refining (Unlu and Mezreli, 2011). Pink bollworm being an emerging pest of Bt cotton in India, very few attempts of use of mating disruption technology have been tried. A two- year detail study on semi-large area of cotton was carried out in Marathwada region of Maharashtra for management of PBW using PB Rope L (Anonymous, 2019). Similarly, the SPLAT-PBW mating disruption tool was used successfully at Dharwad (Karnataka) (Sreenivas *et al*., 2021). However, mega-demonstration of mating disruption conducted in

Table 3: Seed cotton yield in five clusters as influenced by PBKnot

S. No.	Villages	Cluster No.	PBKnot Treated fields Seed Cotton Yield (Kg/Ha)	Control Fields Seed Cotton Yield (Kg/Ha)	Additional Seed Cotton Yield due to PBKnot (kg/Ha)	Additional Income (Rs/Ha)
1	Waroda	I	1400	900	500	49,500
2	Waroda	II	1390	990	400	39,600
3	Adasa	III	1563	913	665	65,835
4	Adasa	IV	1240	800	440	43,560
5	Methapanjara	V	1560	820	740	73,260
Average			1430	880	550	54,450

*Average rate from (2021-22) season crop Rs. 9,900 per quintal seed rate (1 quintal =100kg) this study is unique in many aspects, like; 60 acres of 5 clusters data generation, participation of farmers right from sowing, application of the PBKNOT, counting the trapped moths of PBW, studying the damages of the pest, till collecting precise yield data and help in monitoring the project.

Conclusion

PBKNOT, a pheromone- based formulation with the simplicity of tying as a knot (called *Bandhan* locally) around the main stem was found effective in checking the mating process of pink bollworm of cotton. A mega-demonstration of the technology was conducted on 300 acres organized in 5 clusters of 60 acres each in farmers field in three villages around Nagpur (Maharashtra) during the epidemic year of the pest. The technology helped in reducing the flower damage by 52%, green boll damage by 59% and locule infection by 49%. Mating disruption to the tune of 87% was achieved which resulted in overall increase of seed cotton yield by 2970 kg /acre. Being an ecofriendly technology, the mega demonstration has paved ways for large scale adoption of the system as is evident by visits of large number of farmers to the demonstration fields. This approach is best suited also in integrated pest management of pink bollworm of cotton.

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Efficacy of different botanical extracts against insect pests of pea (Makhyatmubi) of Manipur

Sujeeta Kharibam, Kangjam Bumpy and R K Imotomba

Department of Entomology
Pandit Deen Dayal Upadhyay Institute of Agricultural Sciences, Utlou, Bishnupur 795 134, Manipur, India

Abstract

The studies were carried out to assess the effect of four indigenous plant extracts viz., *neem, marigold, periwinkle and wild sage at two different concentrations (5 and 10 per cent). A control and standard check (Thiamethoxam 25 WG) were also maintained. Three insect pests* viz., *aphid (*Acyrthosiphon pisum*), leaf miner* (Chromatomyia horticola*) and gram pod borer* (Helicoverpa armigera*) were found infesting the pea crop during the study period. Among the botanicals tested, neem 10 per cent was found to be the best effective treatment for managing all the insects as it recorded an overall mean aphid population of 3.01 reductions which was closely followed by neem 5 per cent (3.10). Periwinckle 5 per cent was found to be the least effective treatment with overall 3.59 mean populations. Similarly, neem 10 percent was proved to be effective against leaf miner and gram pod borer recording 0.87 and 1.22 overall mean population respectively which was closely followed by neem 5 per cent (0.93 and 1.27 respectively), marigold 10 per cent (1.04 and 1.30 respectively) and marigold 5 per cent (1.56 and 1.37 respectively). Highest seed yield was recorded in neem 10 per cent (427.73 kg/ha) and was closely followed by neem 5 per cent (424.96 kg/ha) while the lowest was observed in treatment with periwinkle 5 per cent (333.30 kg/ha) and was closely followed by periwinkle 10 per cent (336.06 kg/ha) and wild sage 5 per cent (363.86 kg/ha). In this study, neem was proved to be the best botanical for managing the insect pests of pea.*

Keywords: Aphids, botanicals, *Helicoverpa armigera*, leaf miner, pea, pod borer.

Introduction

Pea (*Pisum sativum* Linnaeus) is an annual plant and belongs to the family Fabaceae. It is cool season crop mostly grown in all states of the country during *Rabi* season and because of its taste, nutritive value, fast growth and high yield, this crop is patronized throughout the world. India is one of the major pulse growing countries in the world producing about 22.40 million tonnes from an area of 29.30 million hectare (Anonymous, 2017). India is the second largest producer of pea in the world and account for 21 percent of the world production. Uttar Pradesh is the major field pea growing state. It alone produces about 49 percent of pea produced in India. In Manipur, field pea is the major pulse crop grown in 26,000 hectare area occupying about 85 percent of the total pulses area (Anonymous, 2015). In Manipur, pea variety Makhyatmubi yields up to 15-20 tonnes per hectare (Bijaya *et al.,* 2021). Insects like pea pod borer, *Etiella zinckenella* Treitschke (Lepidoptera:Pyralidae), pea leaf miner, *Chromatomyia horticola* Blanchard (Diptera:Agromyzidae), aphid, *Acrythosiphon pisum* Harris (Hemiptera:Aphididae), pea stem fly, *Ophiomyia phaseoli* Blanchard, (Diptera:Agromyzidae), Pod fly *Melanagromyza obtusa* Malloch (Diptera:Agromyzidae) and tobacco caterpillar, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) are serious pests and cause substantial loss to the crop (Mittal and Ujagir, 2007). Severe infestation of aphid, *A. pisum* Harris on pea can cause stunting, deformation, wilting and even death of the plant. Aphids can also feed on pods, causing them to curl, shrink and partially filled pods (Ali *et al.,* 2005). Pea leaf miner, *C. horticola* is one of the serious pests of pea causing 90 percent damage to the pea crop by mining young leaves leading to stunted growth of plants resulting in lower flowering and pod formation (Rizvi *et al.,* 2015). Gram pod borer, *H. armigera* Hubner is a polyphagous and one of the most devastating crop pest worldwide. It attacks a wide range of food, fibre, oil and fodder crops as well as many horticultural and ornamental crops (Halder *et al.,* 2009). Botanical pesticides are biodegradable and their use in crop protection is a practical sustainable alternative (Delvin and Zettel, 1999). Many botanical products have been found to act as oviposition and feeding deterrents, ovicidal and larvicidal agents against diverse range of insect pests. Botanical pesticides are unique because it can be produced easily by farmers and small industries (Roy *et al.,* 2005). Keeping in view, the present study was carried out to find practical and eco friendly pest management options in pea.

Materials and methods

The present experiment was carried out at the field of Pandit Deen Dayal Upadhyay Institute of Agricultural Sciences, Utlou, Manipur, during the *Rabi* season from November 2019 to March 2020. The field trial with Pea local cultivar Makhyatmubi was conducted in Randomized Block Design (RBD) consisting of ten treatments and three replications. The treatments were neem (*Azadirachta indica*), marigold (*Tagetus minuta*), periwinkle (*Vinca rosea*), wild sage (*Lantana camara*) and Thiamethoxam 25% WG (standard check) and water as a control (Table 1). Each experiment consists of total 30 plots, 2m 1.2m (2.4m²) per plot size and the total area covered 10m 8m (80m²). Row to row and Plant to plant spacing was 30cm and 15cm respectively. All other management practices were done as per the agronomic recommendation.

Table 1: Details of the treatments

Treat. No.	Treatments name	Dose %
T1	Neem (*Azadirachta indica* A.Juss.)	5
T2	Neem (*Azadirachta indica* A.Juss.)	10
T3	Marigold (*Tagetus minuta* L.)	5
T4	Marigold (*Tagetus minuta* L.)	10
T5	Periwinkle (*Vinca rosea* L.)	5
T6	Periwinkle (*Vinca rosea* L.)	10
T7	Wild sage (*Lantana camara* L.)	5
T8	Wild sage (*Lantana camara* L.)	10
T9	Thiamethoxam 25%WG (Standard check)	0.0025
T10	Control	-

Preparation of plant extracts

The plant materials used in the experiment were fresh leaves of neem, marigold, periwinkle and wild sage. They were collected from local area near PDDUIAS campus. Collected leaves were washed with water and were sun dried for 2-3 days. The dried plant materials were grounded to powder with the help of an electrical grinder. Five gram of each plant powdered sample were mixed with 100 ml of water and soaked overnight. After 24 hrs, the mixture was filtered through muslin cloth and the extract thus obtained was made up to the required spray volume of 5% and 10%. From the stock solution, 5ml and 10ml of the solution were taken and further diluted to desired concentration of 5 and 10%. Concentration of 5% and 10% were prepared with water for experimental evaluation. The extract was kept in a glass bottle/jar at room temperature until further use. To obtain different concentration of plant products, the following formula was applied

$$= \frac{\text{Concentration required (\%)} \times \text{Amount required (ml)}}{\text{Concentration technical material (EC)(ml)}} \times 100$$

Determination of amount of insecticides

The required amount of insecticides was calculated by using the formula as given below:

$$V = \frac{C \text{ X } A}{\%\text{ a.i.}}$$

Where, V = volume of the insecticide

C = concentration required

A = amount of spray solution needed

% a.i. = percent of active ingredient of the insecticide

Observation on aphids

The estimation of aphid population was based on the numerical count method adopted by Dotasara *et al.,* (2017). For recording the aphid population, leaves were grasped at the petiole by thumb and fore finger and twisted until entire underside of the leaves were clearly visible. The observation of aphid populations were recorded at 10 days intervals. The mean number of aphids was recorded by taking the aphid population (both nymph and adult) per leaf present on each leaf (upper, middle, lower) from each of randomly 10 selected tagged plants per plot. Initially aphids appeared on the plot of pea in second week of December 2019 till the maturing stage of the crop. Count of aphid (nymph and adult) was recorded at 10, 20 Days after spraying. The percentage reduction of pest population over control is calculated by using following formula.

$$\text{Percentage population reduction} = \left(1 - \frac{Ta}{Ca} \times \frac{Cb}{Tb}\right) \times 100$$

Where, Ta= number of insects on treated plots after insecticidal application

Tb = number of insects on treated plots before insecticidal application

Ca = number of insects on untreated plot after insecticidal application

Cb = number of insects in untreated plot before insecticidal application

Observation on pea leaf miner

Five plants per plot were randomly selected and tagged for observation. The observation on total number of leaves as well as number of infested leaves of selected plants were recorded from mid December to flowering stage of crop. The observations on pea leaf miner population were recorded at 10 days interval. Percent damage caused by leaf miner was counted and converted into percent damage by the following formula (Shakur *et al*. 2007).

$$\text{Percent damage} = \frac{\text{No. of damage leaves}}{\text{Total number of leaves}} \times 100$$

Observation on pod borer

Number of larvae was recorded from 10 randomly selected plants in each treatment through visual counting by opening leaves from healthy pea plants. Count of *H. armigera* larvae were recorded at 10 and 20 days after spray. The population peaks generally corresponds to the full bloom and pod formation stage of pea. The immature as well as the mature stages of insect pests present on them were counted at 10 days interval, starting from week of the month till the maturing crop. The damage due to *H. armigera* could be distinguished by the presence of large size holes on the pods. The grains were partially or wholly eaten by larvae. Data on infested pod for the individual treatments were also recorded using the following formula (Kumar *et al.,* 2019).

$$\text{Percent infested pod} = \frac{\text{Number of infested pods}}{\text{Total number of pods}} \times 100$$

Yield

Seed weight per plot was measured from the harvested seeds of pea and then converted into kilogram per hectare.

The grain yield was calculated by using the formula adopted by FAO (1995).

$$\text{Grain yield (kg/ha)} = \frac{\text{Plot yield (kg)} \times 10000}{\text{plot size sq. m.}}$$

The avoidable loss and increase in grain yield over untreated check was calculated for each treatment by using the following formula (Pawar *et al.,* 1984)

$$\text{Increase in yield (\%)} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in control}} \times 100$$

$$\text{Avoidable losses (\%)} = \frac{\text{Highest yield in treated plot} - \text{Yield in treatment}}{\text{Highest yield in treated plot}} \times 100$$

Results and discussion

Occurrence of insect pests in field of pea (Makhyatmubi)

The occurrence of insect pests in the present study was recorded by observing the incidence of the respective insect pests and their nature of damage. Significant population of insect pests *viz.,* aphid, pea leaf miner and gram pod borer *etc.* were recorded (Table 2).

Table 2 List of Insect pests of pea observed in the field during the study period

S. No.	Name of insect pests	Order & Family	Stage(s) of insects	Site of infestation	Status
1.	Aphid *Acyrthosiphon pisum* (Harris)	Aphididae (Hemiptera)	Adult and nymph	Sap sucker on leaves, shoot	Major
2.	Pea leaf miner *Chromatomyia horticola* (Goreau)	Agromyzidae (Diptera)	Larvae	Leaves	Minor
3.	Gram pod borer *Helicoverpa armigera* (Hubner)	Noctuidae (Lepidoptera)	Larvae	Pods	Stray

Effect of biopesticides on aphid population

In the present study, neem 10 per cent was found to be most effective in reducing aphid population on pea and resulted up to 3.01 overall mean population reduction. Neem 5 per cent, marigold 10 per cent and marigold 5 per cent were effective next to neem 10 per cent in their efficacy and depicted up to 3.10, 3.16 and 3.21 overall mean in aphid population respectively (Table 3). The present results are in agreement with that of Megersa (2016) who reported that Neem 10 per cent and Neem 5 per cent as the most effective botanicals against aphid. Chandel *et al.* (2012) and Mvumi *et al.* (2018) also reported that leaf extracts of *Lantana* showed aphid mortality and can be used as alternatives to chemical which corroborate with the present investigation. *L. camara* and Periwinkle were least effective in comparison to Neem.

Table 3: Effect of different botanical extracts on aphids in pea during *rabi* season 2019-20

S. No.	Treatments	Vegetative Stage		Flowering Stage		Pod formation		Overall mean
		3 DAS	7 DAS	3 DAS	7 DAS	3 DAS	7 DAS	
1	Neem 5%	4.67 (2.16)	4.24 (2.05)	3.20 (1.78)	2.98 (1.72)	2.00 (1.41)	1.52 (1.44)	3.10
2	Neem 10%	4.62 (2.15)	4.23 (2.05)	2.98 (1.72)	2.96 (1.71)	1.90 (1.37)	1.41 (1.18)	3.01
3	Marigold 5%	4.68 (2.16)	4.46 (2.11)	3.24 (1.80)	3.18 (1.77)	2.11 (1.45)	1.60 (1.26)	3.21
4	Marigold 10%	4.68 (2.16)	4.38 (2.09)	3.21 (1.79)	3.06 (1.74)	2.10 (1.43)	1.53 (1.23)	3.16
5	Periwinkle 5%	5.07 (2.25)	4.83 (2.19)	3.45 (1.85)	3.50 (1.87)	2.60 (1.60)	2.10 (1.44)	3.59
6	Periwinkle 10%	5.05 (2.24)	4.68 (2.16)	3.36 (1.83)	3.26 (1.80)	2.53 (1.59)	2.10 (1.44)	3.49
7	Wild sage 5%	4.73 (2.17)	4.63 (2.15)	3.40 (1.84)	3.31 (1.81)	2.50 (1.58)	1.83 (1.35)	3.40
8	Wild sage 10%	4.71 (2.17)	4.56 (2.13)	3.36 (1.82)	3.26 (1.80)	2.23 (1.49)	1.76 (1.32)	3.31
9	Thiamethoxam 25 WG	4.08 (2.02)	4.20 (2.04)	2.56 (1.59)	2.33 (1.52)	1.62 (1.26)	1.36 (1.16)	2.69
10	Control	5.43 (2.33)	5.10 (2.25)	6.66 (2.58)	6.83 (2.61)	6.93 (1.63)	6.96 (2.63)	6.31
	SEm±	0.04	0.03	0.03	0.06	0.06	0.06	0.25
	C.D. (0.5)	0.13	0.11	0.11	0.20	0.18	0.19	0.74
	C.V. (%)	3.49	2.97	3.35	5.87	6.13	6.77	17.99

Figures in the parantheses are square root transformed values; DAS- days after spray

Effect of botanicals on leaf miner population

Experiments were carried out in the field using different plant extracts to observe its effect on leaf miner. The data presented in Table 4 indicate that the overall impact of plant extract was quite visible in overall mean. Neem 10 per cent recorded lowest mean population (0.87) followed by neem 5 per cent (0.93), marigold 10 per cent (1.04) and marigold 5 per cent (1.22). Periwinkle 5 per cent (1.56) was found to be the least effective botanical against leaf miner. The present findings are in partial agreement with the findings of Singh and Saravanan (2008) who reported that NSKE (97.35%) and Neem oil (91.41%) reduced leaf miner population. Fitiwy *et al.* (2019) also observed neem seed extract as the best botanical in controlling leaf miner infestation which supports our present investigation.

Table 4: Effect of different botanical extracts against leaf miner in pea during *rabi* season 2019-20

S. No.	Treatments	Vegetative Stage		Flowering Stage		Overall mean
		3 DAS	7 DAS	3 DAS	7DAS	
1	Neem 5%	1.66 (1.28)	1.32 (1.14)	0.53 (0.63)	0.23 (0.47)	0.93
2	Neem 10%	1.54 (1.23)	1.27 (1.12)	0.49 (0.65)	0.18 (0.42)	0.87
3	Marigold 5%	2.00 (1.41)	1.47 (1.21)	1.11 (1.05)	0.31 (0.55)	1.22
4	Marigold 10%	1.80 (1.33)	1.36 (1.16)	0.73 (0.78)	0.28 (0.50)	1.04
5	Periwinkle 5%	2.17 (1.47)	2.00 (1.41)	1.39 (1.70)	0.68 (0.79)	1.56
6	Periwinkle 10%	2.13 (1.45)	1.80 (1.34)	1.24 (1.11)	0.62 (0.74)	1.44
7	Wild sage 5%	2.06 (1.43)	1.55 (1.23)	1.20 (1.09)	0.55 (0.62)	1.34
8	Wild sage 10%	2.06 (1.43)	1.53 (1.23)	1.18 (1.08)	0.28 (0.49)	1.26
9	Thiamethoxam 25 WG	1.37 (1.17)	1.20 (1.09)	0.38 (0.61)	0.17 (0.41)	0.78
10	Control	2.18 (1.47)	2.16 (1.47)	3.06 (1.74)	3.26 (1.80)	2.66
	SEm±	0.06	0.03	0.07	0.06	0.20
	C.D. (0.5)	0.17	0.11	0.23	0.20	0.58
	C.V. (%)	6.70	4.44	10.78	11.42	30.61

Figures in the parantheses are square root transformed values; DAS- days after spray

Effect of botanicals on gram pod borer population

Results on effect of botanicals on gram pod borer has been presented in Table 5. The data showed similar trend as far as treatment of botanicals is concerned. The overall mean was lowest (1.22) in neem 10 per cent. This was followed by neem 5 per cent, marigold 10 per cent and marigold 5 per cent which were statistically similar in order of overall gram pod borer infestation, recording 1.27, 1.30 and 1.37 mean larval population respectively. Highest infestation was observed at periwinkle 5 per cent (1.56) which was inferior to all other tested botanicals. In control set of experiment 2.14 mean larval population was observed. Kumar *et al*. (2019) also reported NSKE @ 5% (3.50), neem leaf extract @ 5% (4.0) and neem oil @ 2% (4.3) and nimbicidine @ 2% (4.5) to reduced mean larval population of *H. armigera* in chickpea which corroborate our present findings. Bijewar *et al.* (2018) stated that *Lantana* @ 5% (4.63) was the least effective treatment in reducing damage by gram pod borer which is somewhat similar to our present findings where Lantana 5 per cent and 10 per cent overall mean population were higher than other botanicals recording 1.48 and 1.41 mean larval population. It was noted that lower pod damage was recorded in plots treated with neem 10 and 5 per cent compared to control plots and treatment with Periwinkle 10 and 5 per cent. The lower pod damage in these plots might be due to the insecticidal properties of neem such as repellent, deterrent to oviposition or feeding with unpleasant odour or irritants and having adverse toxicity effects to insect pests making the host unpalatable. Contrary to this, Halder *et al.* (2009) reported that *V. rosea* were more effective in reducing growth larval toxicity as well as inhibiting adult emergence of *H. armigera* in comparison to neem oil and NSKE which is in contrast to our present investigation.

Table 5: Effect of different botanical extracts on Pod Borer in pea during *rabi* season 2019-20

S. No.	Treatments	Pod Formation stage		Overall mean
		3 DAS	7 DAS	
1	Neem 5%	1.27 (1.13)	1.27 (1.13)	1.27
2	Neem 10%	1.25 (1.11)	1.20 (1.09)	1.22
3	Marigold 5%	1.41 (1.18)	1.34 (1.16)	1.37
4	Marigold 10%	1.31 (1.14)	1.29 (1.14)	1.30
5	Periwinkle 5%	1.68 (1.30)	1.45 (1.20)	1.56
6	Periwinkle 10%	1.64 (1.27)	1.43 (1.20)	1.53
7	Wild sage 5%	1.56 (1.24)	1.40 (1.18)	1.48
8	Wild sage 10%	1.43 (1.20)	1.39 (1.17)	1.41
9	Thiamethoxam 25 WG	1.20 (1.09)	1.12 (1.06)	1.16
10	Control	2.13 (1.46)	2.16 (1.47)	2.14
	SEm±	0.04	0.03	0.04
	C.D. (0.5)	0.12	0.09	0.14
	C.V. (%)	4.74	3.71	4.32

**Figures in the parantheses are square root transformed values; DAS- days after spray

Effect of different botanicals on yield

In response to lower larval population and pod damage, maximum yield were recorded from plots treated with neem 10 per cent (427.73 kg/ha) except Thiamethoxam 25 WG (Standard check) (466.63 kg/ha) and was closely followed by neem 5 per cent (424.96 kg/ha) which were statistically significant with one another (Table 6). This findings corroborate with that of Melesse and Singh (2012) and Gemmeda *et al.* (2015) who reported highest yield in NSKE 10% (1312 kg/ha) and Neem (2.17 t/ha) treated plots in field pea. Similarly, Bhatta *et al.* (2019) reported highest yield (2.05 t/ha) from neem extract treated plots followed by tobacco extract (2.02 t/ha) whereas lowest yield was in untreated (1.13 t/ha) which is in partial agreement with the present findings. In line with our results, *A. indica* alcoholic seed extract recorded highest yield (1286.0 kg/ha) in chickpea as reported by Fite *et al.* (2020). Among the botanicals, neem extracts proved to be the best effective treatment in all the three insects due to its antifeedant and repellent properties. These indigenous plant extracts can be used in the field since they are less toxic, much safer than chemical insecticide which causes pest outbreak and resurgence. So, by incorporating these botanicals, the application of chemical insecticides can be reduced to a minimum level. Thus, the locally available indigenous plant extracts would greatly benefit the resource poor farmers of Bishnupur District and further research needs to focus on mechanism of their mode of action, ease of product availability and consideration for implementing as a part of IPM tool in pest management of pea.

Table 6: Effect of different botanical treatments on yield in pea during *Rabi* 2019-20

S. No.	Treatments	Yield kg/ha	Increase in yield over control %	Avoidable losses %
1	Neem 5%	424.96	35.39	8.92
2	Neem 10%	427.73	36.28	8.33
3	Marigold 5%	383.30	22.12	17.85
4	Marigold 10%	391.63	24.77	16.10
5	Periwinkle 5%	333.30	6.19	28.57
6	Periwinkle 10%	336.06	7.10	27.98
7	Wild sage 5%	363.86	15.93	22.02
8	Wild sage 10%	372.20	18.58	20.23
9	Thiomethoxam 25 WG	466.63	48.67	0
10	Control	313.86	0	32.73
	Sem ±	0.01		
	C.D. (0.5)	0.04		
	C.V. (%)	28.92		

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Comparative efficacy of different insecticides, biopesticides and plant extracts against the cutworms

S D Sharma and Kawartej Singh Sidhu

Department of Entomology, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176062, Kullu District, Himachal Pradesh, India.
Email: sukhdevsharma40@gmail.com

Abstract

A field experiment was conducted at Hill Agricultural Research and Extension Centre, Bajaura (1100 m a.m.s.l.), Kullu, Himachal Pradesh during Kharif *season of 2018 on maize crop (variety Girija) to evaluate different insecticides, biopesticides and plant extracts against the cutworms infesting maize crop. The results revealed that the seedling mortality by cutworms in different treatments varied from 0.00 to 9.91 per cent as compared to control with 17.40 per cent. Treatment consisting of seed treatment with imidacloprid (6 ml/kg) followed by foliar spray of chlorpyriphos (2.0 ml/L) was the most effective treatment giving the best safety to the crop and resulting in no seedling mortality. There was 100 per cent reduction in the cutworm population over control in this treatment with the highest grain yield (57.26 q/ha). This treatment was followed by a treatment (T3) consisting of seed treatment with thiomethoxam 7 g/kg of seed resulting in 1.89 seedling mortality and thus recording 89.13 per cent reduction in the cutworm population over control with grain yield of 55.05 q/ha. The cost benefit ratio was highest in case of treatment T1 (seed treatment with imidacloprid) with the net monetary returns of Rs. 70788/ha.*

Keywords: Cutworms, economics, efficacy, evaluation, maize, plant extracts.

Introduction

Among the many species of insect pests that damage maize crop, cutworms (*Agrotis* spp.) (Lepidoptera: Noctuidae) are serious polyphagous and cosmopolitan pests of economic importance attacking it and a large number of other crops throughout the world including in India (Wright *et al*., 2013; Sharma, 2016). In India, these insects are active from October to March in the Indian plains and during summer season in the mountainous regions of the country (Atwal and Dhaliwal, 2002). In Himachal Pradesh cutworms are the most serious insect pests of maize causing 23.92 per cent damage to this crop (Thakur and Kashyap, 1992). Here maize is mainly grown in *Kharif* season under rainfed conditions and is severely damaged by cutworms in the early stages of growth (upto 4 leaf stage). Evaluation of different insecticides and biopesticides by using them as seed treatment, soil application at the time of sowing and spraying them immediately after the crop emergence is of great significance to curb the incidence of cutworms and finding their effective control in maize crop. The present studies were therefore undertaken to evaluate and compare the bio-efficacy of different insecticides, biopesticides and locally available plant extracts for suitability against this pest.

Materials and methods

A field experiment was conducted at HAREC, Bajaura (1100 m a.m.s.l.), Kullu, Himachal Pradesh during *Kharif* season of 2018 on maize crop (variety Girija) in a Randomized Block Design with nine treatments each replicated thrice to evaluate various insecticides, biopesticides and plant extracts against cutworms with a plot size of 3x3m and spacing of 60 x 20 cm. All the agronomic practices were adopted uniformly for all treatments. There were nine treatments (including a control) each replicated thrice. The seed treatment in case of T_1, T_2, T_3 and T_6 was done in a plastic pot to provide a uniform thin film of insecticide on the seed surface. Sowing was done after shade drying of seed on a polyethylene sheet. Nine treatments including control were: T_1: Imidacloprid 600 FS @ 6 ml/kg of seed as seed treatment ; T_2: Thiomethoxam 70 WS @ 5 g/kg of seed as seed treatment ; T_3: Thiomethoxam 70 WS @ 7 g/kg of seed as seed treatment ; T_4: Carbofuran 3G @ 30 kg/ha as product in soil at sowing in furrows ; T_5: Quinalphos 25 EC @ 2.0 ml/l of water as product at crop emergence ; T_6: Imidacloprid 600 FS @ 6 ml/kg of seed as seed treatment followed by surface application of Chlorpyriphos 20 EC @ 2.0 ml/l of water as product at crop emergence;

T_7: Neembaan (azedarachtin 0.15% EC) which was applied at crop emergence as surface application @ 2.5 ml/l of water; T_8: Sweet flag (*Acorus calamus*) 5% RE (Root extract) @ 5 ml/L at crop emergence. Sweet flag extract was prepared by shade drying of the roots of *Acorus calamus* plants for 5-6 days and then powdered in a mixer grinder and powdered material was stored at room temperature. About 48 hours before use, weighed quantity of the powdered test material was dissolved in water in a bucket to which cow urine @ 3% was also added. The bucket was stirred intermittently. Before spray the solution was sieved through muslin cloth. Residue in the cloth was thoroughly washed to remove all the extract. Final value of the extract was made to the desired level depending upon the concentration of extract to be sprayed. T_9 consisted of control (no spray). The initial plant population was recorded at germination stage in each plot. Per cent plant damage/cut plants were recorded at 2 and 4 leaf stages of the crop and were analyzed by taking the angular values. The grain yield was recorded in each plot and analyzed by converting the values in to q/ha. Average larval population/ unit area (1x1 m^2) was also recorded at 4 leaf stage of the crop. The data were analyzed statistically after appropriate transformations.

Results and discussion

The results recorded on the effect of different insecticides, biopesticides and plant extracts on the cutworms in maize crop have been presented in Table 1. The seedling mortality due to cutworms under different treatments was recorded at 4, 7 and 11 days after germination and was pooled together. The pooled seedling mortality in different treatments varied from 0.00 to 9.91 per cent as compared to control with 17.40 per cent mortality. Treatment T_6 consisting of seed treatment with imidacloprid 6 ml/kg followed by surface application of chlorpyriphos 2.0 ml/L was the most effective treatment resulting in zero seedling mortality and thus recording 100 per cent reduction in the cutworm population over control. This treatment was followed by T_3 consisting of seed treatment with thiomethoxam 70WS resulting in 1.89 seedling mortality and thus recording 89.13 per cent reduction in the cutworm population over control. These treatments were followed by T_4, T_5, T_1, T_2, T_7 and T_8 with 1.96, 2.15, 3.97, 4.20, 8.20 and 9.91 per cent seedling mortality respectively. These further recorded 88.73, 87.64, 77.18, 75.86, 52.87 and 43.04 per cent reduction in the cutworm population over control respectively.

The data revealed that the highest grain yield of maize (57.26 q/ha) was recorded in the treatment T_6 consisting of seed treatment with imidacloprid (600 FS) followed by surface application of chlorpyriphos (30 EC) which was statistically at par with T_3 (55.05 q/ha), T_4 and T_5. Among the various treatments T_8 recorded the lowest yield (43.53 q/ha) which was statistically at par with T_7 (44.75 q/ha). The grain yield in different treatments varied between 37.17 and 57.26 q/ha. Treatment T_6 recorded the highest per cent increase (54.04%) over the control with 35.09 per cent avoidable losses followed by T_3 which recorded 48.10 per cent increase over the control with 32.48 per cent avoidable losses. T_4 and T_5 recorded 54.94 and 54.36 grain yield with 47.80 and 46.25 per cent increase over control, respectively. T_7 and T_8 being a biopesticide and plant extract (root extract of rhizomes of sweet flag), recorded 20.40 and 17.11 per cent increase over control with 16.94 and 14.61 per cent avoidable losses, respectively which was quite low as compared to the other treatments. T_1 and T_2 recorded a grain yield of 48.41 and 48.32 with 30.24 and 30.00 per cent increase over control and 23.21 and 23.07 per cent avoidable losses, respectively. The increased efficacy resulting in higher productivity in T_6, which comprised of two chemicals viz. imidacloprid used as a seed treatment and chlorpyriphos as surface application used immediately after emergence of maize seedlings, might be due to their combining and cumulative action against the cutworms which lasted for a prolonged period as compared to other treatments. The observations regarding the higher and better efficacy of two chemicals by their combined use of seed treatment and aerial spraying are in conformity to those of Zaki and Andrabi (1999) who reported the use of carbofuran (seed treatment) and deltamethrin (aerial spraying) quite effective as compared to other chemicals. The present findings are more or less in conformity to those of Bhagat *et al.* (2008) who evaluated the efficiency of some biopesticides and insecticides for the management of *A. ipsilon* in Jammu on maize crop and concluded that seed treatment with chlorpyriphos, imidacloprid and insecticidal dust application of chlorpyriphos attributed to higher yield and less plant mortality as compared to other treatments. Similarly, Sharma *et al.* (2002) evaluated the efficacy of different insecticides against *Agrotis* spp. in wheat and reported that the application of chlorpyriphos after impregnation on sand and folidol dust was superior over other treatments. Ali *et al*. (2011) evaluated four different insecticides and concluded that Provido (Imidacloprid) and Lavrin (thiodicarb) gave the best results. Earlier, Shakur *et al.* (2007) reported that poison bait (Diptrex+ sugar + rice husk) application was effective and safe to control cutworms in potato crop and this practice could be incorporated in the IPM of potato for minimum and target use of pesticide. The present findings are not in conformity to those of Zaki *et al.* (2007) who reported that imidacloprid used against the cutworms recorded the maximum tuber yield in potato and Mishra and Singh (2006) who reported imidacloprid to be the most effective and significantly superior to the other treatments by recording the lowest potato tuber damage (2.52%) and the highest tuber yield (228.33q/ha) followed by chlorpyriphos. The present findings find some support from the results of Tripathi *et al.* (2003) who reported chlorpyriphos @ 2.0 kg/ha to be the most effective treatment in terms of protection and production. Sharma (2016) reported that mixture consisting of methyl parathion and carbofuran to be the most effective in both cabbage and tomato crops minimizing the infestation of cutworms significantly. Sharma and Lal (2017) also reported the increased and better efficacy of mixtures of ecofriendly pesticides *viz*., crude leaf extract prepared from five plants *viz*., *Cannabis sativa* (bhang), *Roylea cineria* (karvi), *Juglans regia* (walnut), *Nerium* sp. (kaner) and *Melia azedarach* (darek) as compared to use of single ecofriendly plant extract *viz*., crude leaf extract of *Melia azedarach* (darek) for the control of various caterpillars infesting cabbage crop.

Table 1: Evaluation of different insecticides, biopesticides and plant extracts against the cutworms

Treatments	Seedling mortality (%)	Per cent reduction over control	Yield (q/ha)	Per cent increase over control	Avoidable losses
T_1 (Imidacloprid 600 FS)	3.97 (2.24)	77.18	48.41	30.24	23.21
T_2 (Thiomethoxam 70 WS)	4.20 (2.28)	75.86	48.32	30.00	23.07
T_3 (Thiomethoxam 70 WS)	1.89 (1.70)	89.13	55.05	48.10	32.48
T_4 (Carbofuran 3G)	1.96 (1.72)	88.73	54.94	47.80	32.34
T_5 (Quinalphos 25 EC)	2.15 (1.78)	87.64	54.36	46.25	31.62
T_6 (Imidacloprid 600FS + Chlorpyriphos 20 EC)	0.00 (1.00)	100.00	57.26	54.04	35.09
T_7 (Neembaan 0.15% EC)	8.20 (3.03)	52.87	44.75	20.40	16.94
T_8 (Sweet flag 5% ARE)	9.91 (3.30)	43.04	43.53	17.11	14.61
T_9 (Control)	17.40 (4.29)		37.17		
CD (P=0.05)	0.18		4.17		

Note: Figures in parentheses are square root transformations

The data on the economics of different treatments used for the control of cutworms is presented in the Table 2. It revealed that the benefit: cost ratio varied from 16.4 to 38.7. It was lowest in case of seed treatment of imidacloprid followed by foliar application of chlorpyriphos (T_6) and highest in case of seed treatment with imidacloprid (T_1) with the net monetary returns of Rs. 70788/ha. The lowest benefit: cost ratio of T_6 is mainly attributed to comparatively a greater number of man days involved for seed treatment followed by surface application of the chlorpyriphos at the time of seedling emergence. This treatment was followed by neembaan (T_7) in benefit: cost ratio which was low due to the decrease in the grain yield. Whereas, the highest benefit: cost ratio of T_1 is attributed to its very cheap price of the chemical as compared to other insecticides. The present findings are in conformity to those of Mishra and Singh (2006) who reported highest net monetary returns (Rs 54356.0/ha) by using imidacloprid and Zaki *et al.* (2007) reported highest cost: benefit ratio of 1:29.95 with imidacloprid. However, Tripathi *et al* (2003) reported highest mean net return (Rs. 41488.0/ha) and the highest cost: benefit ratio (CBR) of 1:58.59 in chlorpyriphos 20EC (2.0 kg/ha) treated plots, applied twice in initial growth stage and subsequent application at tuberization stage of the potato crop.

Treatment consisting of seed treatment with imidacloprid (6 ml/kg) followed by foliar spray of chlorpyriphos (2.0 ml/L) was the most effective treatment giving the best safety to the crop and resulting in no seedling mortality. The cost benefit ratio was highest in case of treatment T1 (seed treatment with imidacloprid) with the net monetary returns of Rs. 70788/ha. This knowledge will be useful for the effective management of cutworms in maize and to get higher yield.

Table 2: Economics of different treatments used for the control of cutworms infesting maize

Treatments	Seed yield (q/ha)	Cost of treatment (Rs. /ha)	Gross returns	Net returns	Benefit: Cost ratio
T_1 (Imidacloprid 600 FS)	48.41	1827	72615	70788	38.7
T_2 (Thiomethoxam 70 WS)	48.32	2135	72480	70345	32.9
T_3 (Thiomethoxam 70 WS)	55.05	2455	82575	80120	32.6
T_4 (Carbofuran 3G)	54.94	4335	82410	78075	18.0
T_5 (Quinalphos 25 EC)	54.36	3307	81540	78233	23.7
T_6 (Imidacloprid 600FS and Chlorpyriphos 20 EC)	57.26	4947	85890	80943	16.4
T_7 (Neembaan 0.15% EC)	44.75	3700	67125	63425	17.1
T_8 (Sweet flag 5% ARE)	43.53	2670	65295	62625	23.5
T_9 (Control)	37.17		55755		

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Identification of effective fungicides for the management of false smut disease of rice

D Ladhalakshmi*, M Srinivas Prasad, Gouri Shankar Laha, Ram Singh, V Prakasam, Jagjeet Singh Lore[2], D Krishnaveni and C Kannan

ICAR-Indian Institute of Rice Research, Hyderabad – 500030, Telangana, India
[1]Department of Agriculture, MM (DU), Mullana, Ambala, Haryana
[2]Punjab Agricultural University, Ludhiana -141004, Punjab, India
Email: Dladha.lakshmi@icar.gov.in; ladhasavitha@gmail.com

Abstract

Rice false smut pathogen Ustilaginoidea virens *(teleomorph:* Villosiclava virens*) replaces the grain into powder form and causes direct economic yield loss. High intensity of the disease was reported from almost all the rice-growing regions of India during the favorable years with conducive climate conditions like drizzling or cooler climate during the booting to flowering stage. With scanty knowledge on host plant resistance, the disease has to be managed with available fungicides to prevent economic yield loss. Field trials were formulated and evaluated the efficacy of nine fungicides through the All India coordinated Rice Improvement Programme at two false smut hot spot locations, viz. CCSHAU Rice Research Station, Kaul, and Punjab Agricultural University, Ludhiana for two successive years (2016 and 2017). Each fungicide was sprayed once at the booting stage, followed by another application at ten days. Among the tested fungicides, azoxystrobin 18.2% + difenoconazole 11.4% w/w SC @ 1.0 ml/l and propiconazole (0.1%) significantly increased the grain yield by reducing the false smut disease severity at tested locations.*

Keywords: False smut, fungicides, management, rice, *Ustilaginoidea virens*.

Introduction

Rice false smut disease is traditionally considered to be minor disease and the occurrence of the smut balls is associated with bumper yield. The reason behind is that the weather conditions, particularly relative humidity or rainfall favorable for disease development, also enhance the good crop growth and grain yield of the crop. The disease is caused by a fungal pathogen known as *Ustilaginoidea virens* (Cooke) Takahashi [teleomorph: *Villosiclava virens* (Nakata) Tanaka & Tanaka]. Large-scale cultivation of high-yielding varieties and hybrids, application of a high dose of N fertilizer, and apparent changes in the climatic conditions also played an important role in the reemergence of the false smut disease (Ladhalakshmi *et al*., 2012; Laha *et al*., 2016). Dodan and Singh (1996) reported a yield loss of 0.2-49% and the loss depends on the rice variety and favorable climatic conditions. However, in extreme cases, reduction in grain yield of a highly susceptible rice cultivar HKR 126 has been observed to vary between 30.0-87.3% depending upon the disease severity (Sunder *et al*., 2005). The pathogen *U. virens* converts individual grain into powder form (smut spores) (Fig 1) and looks like balls. In case of severe incidences of the disease, yellow-colored chlamydospores are observed on the surface of the adjacent healthy rice spikelets and reduce the market price of the grains. Besides direct economic loss, the pathogen also produces mycotoxin (ustiloxin) and reduces the quality of paddy. Up to now, a high level of false smut resistance was not reported in any of the commercially cultivated rice varieties. Hence, the disease has to be managed primarily with the foliar application of fungicides. Several fungicides were reported as effective against false smut (Dodan and Singh 1997; Ladhalakshmi *et al*., 2018). However, continuous research is required to identify new effective fungicides for sustainable management of the disease. In our study, we tested the efficacy of nine commonly available fungicides with two spray schedules (booting stage and at ten days interval) against false smut of rice.

Materials and methods

Field experiments were conducted at two hot spot locations during *Kharif* seasons (2016 and 2017) to know the efficacy of the chemicals. The hot spot locations were CCS Haryana Agricultural University Rice Research Station, Kaul (latitude 29°51'N; 76°39'E and 230.7 m above mean sea level) and Punjab Agricultural University, Ludhiana (latitude 30°54' N; longitude 75°48'E and 247m above mean sea level). Thirty days old seedlings of susceptible rice varieties *viz*., HKR 126 and PR 116 were transplanted at Kaul and Ludhiana, respectively, and the crop was cultivated by adopting the recommended crop cultivation practices. At both locations, the crop was sown between 28th May 2019 and 1st June 2019 and transplanted between 23rd June 2019 and 28th June 2019 to get the maximum disease infection naturally. The experiment was framed in a randomized block design with three replications with a plot size of 10 m^2. Nine fungicides *viz*., azoxystrobin 25 SC @ 1.0 ml/l, difenoconazole 25 EC @ 1.0 ml/l, azoxystrobin 18.2% + difenoconazole 11.4% w/w SC @ 1.0 ml/l, metiram 55% + pyraclostrobin 5% WG @ 1.5 g/l, pencycuron 22.9% @ 1.25 ml/l, tebuconazole 250 EC @ 1.25 ml/l, thiafluzamide 24% SC @ 1.0 ml/l, flusilazole 25% + carbendazim 12.5% @ 1.0 ml/l and propiconazole 25 EC @ 1.0 ml/l were tested under field conditions. The first spray of fungicide was applied at the booting stage, followed by the second spray at ten days intervals. Percentage of infected panicles (disease incidence) and spikelets (disease severity) were recorded as described by Singh and Sunder (2015). Grain yield from the individual plots was recorded as kg/ha. Location-wise, the data was analyzed over the years according to Gomez and Gomez (1984).

Results and discussion

At Kaul, the false smut incidence (percentage of infected panicles) varied between 8.12 to 26.23% during 2016 and 8.66 to 21.20% during 2017, whereas the percentage of infected spikelets ranged from 0.18 to 1.02% during 2016 and 0.23 to 1.06% during 2017. The mean false smut panicle and grain infection were recorded to be 23.72% with 1.04%, respectively. Among the fungicides tested, propiconazole 25 EC @ 1.0 ml/l significantly reduced the mean panicle infection from 23.72% to 8.39% and mean spikelet infection from 1.04% to 0.21%. The fungicide azoxystrobin 18.2% + difenoconazole 11.4% w/w SC @ 1.0 ml/l also performed on par, wherein 11.29% of panicle infection and 0.33% spikelet infection was recorded. Application of propiconazole 25 EC @ 1.0 ml/ l recorded high grain yield as 7517 kg/ha compared to control (6633 kg/ha) and the results were on par with azoxystrobin 18.2% + difenoconazole 11.4% w/w SC @ 1.0 ml/l (7417 kg/ha). Propiconazole and azoxystrobin 18.2% + difenoconazole 11.4% SC reduced the disease incidence by 64.6 and 52.4% and disease severity by 79.8% and 68.3%, respectively, along with 13.3% and 11.8% increase in grain yield of paddy (Table 1).

At Ludhiana, the disease incidence and severity were higher than Kaul during both years. The infected panicles ranged from 10.54 to 32.74% during 2016 and 5.72 to 30.80% during 2017, while infected spikelets varied between 1.80 to 11.80% during 2016 and 0.53 to 4.59% during 2017. Among the tested fungicides, two sprays of propiconazole 25 EC @ 1.0 ml/l at ten days intervals significantly reduced the percentage of mean infected panicles from 31.77% to 8.13% and the mean spikelet infection from 8.19% to 1.19%. Similarly, spraying of azoxystrobin 18.2% + difenoconazole 11.4% w/w SC) @ 1.0 ml/l also performed well in reducing the disease infection both in terms of panicle (10.18%) and spikelet (2.27%) infection. The mean grain yield (5542 kg/ha) was maximum in case of azoxystrobin 18.2% + difenoconazole 11.4% w/w SC) @ 1.0 ml/l followed by propiconazole 25 EC @ 1.0 ml/l (5489) as against 4188 kg/ha in control treatment (Table 2). Propiconazole and azoxystrobin 18.2% + difenoconazole 11.4% SC reduced the disease incidence by 74.4% and 67.9%; disease severity by 85.4% and 72.3%, and increased the grain yield by 31.1% and 32.3% respectively compared to the control treatment. The mean data of both the locations also revealed that propiconazole (T9) and azoxystrobin 18.2% + difenoconazole 11.4% SC (T3) performed well in the terms of reducing the disease incidence and increasing the grain yield (Fig 2). The present study revealed that two foliar applications of propiconazole or azoxystrobin 18.2% + difenoconazole 11.4% at booting and ten days later are important for minimizing the secondary spread of the disease through air-borne chlamydospores in late-emerging panicles and in nearby fields where rice crop is in booting to flowering stage. These findings are supported by the observations made during a survey in village Kandhukur, district Khammam (Telangana), in 2019, where farmers failed to get satisfactory control of false smut disease with a single foliar application of effective fungicide at the booting stage (Author's observation).

The effectiveness of copper fungitoxicants, propiconazole, and trifloxystrobin 25% + tebuconazole 50% against false smut has been established by Pannu *et al*. (2010), Singh and Sunder. (2015) and Ladhalakshmi *et al*. (2018). Similarly, spraying of trifloxystrobin + propiconazole at the heading stage of the rice crop effectively reduced false smut disease (Zhou, 2012). Chen *et al*. (2013) observed a high level of sensitivity of 102 isolates of *U. virens* to different fungicides including propiconazole and tebuconazole. They found that, two sprays of propiconazole 50 EC at 300 g a.i./ha effectively reduced the disease (71.5-74.5%). Spraying of tebuconazole (Shim *et al*., 2001) and application of simaconazole (1.5% granules) at 450-600 g a.i./ha before three weeks of heading (Tasuda *et al*., 2006) have also been observed to be promising against false smut. The fungicide azoxystrobin 18.2% + difenoconazole 11.4% SC at 1 ml/l was found promising against false smut in the present study and has also been reported as effective against sheath blight (Thakur *et al*., 2018; Kumar *et al*., 2018a & b) and neck blast (Singh, 2019) of rice. Propiconazole is known to disturb the biosynthesis of sterols in cell membranes and thereby affect the growth of the fungi. The fungicide, azoxystrobin disrupts the electron transport chain by preventing ATP synthesis and finally affects the respiration of fungi, while difenoconazole inhibits sterol demethylation and inhibits the cell membrane. The use of a combination fungicide with two different modes of action is always safer from the point of view of fungicide resistance development.

The results of this study, concluded that two sprays of propiconazole (0.1%) or azoxystrobin 18.2% + difenoconazole 11.4% w/w SC @ 1.0 ml/l at booting stage, followed by another application at ten days interval can effectively manage false smut disease of rice and increase the grain yield.

Figure 1: Rice panicle infected with *Ustilaginoidea virens*

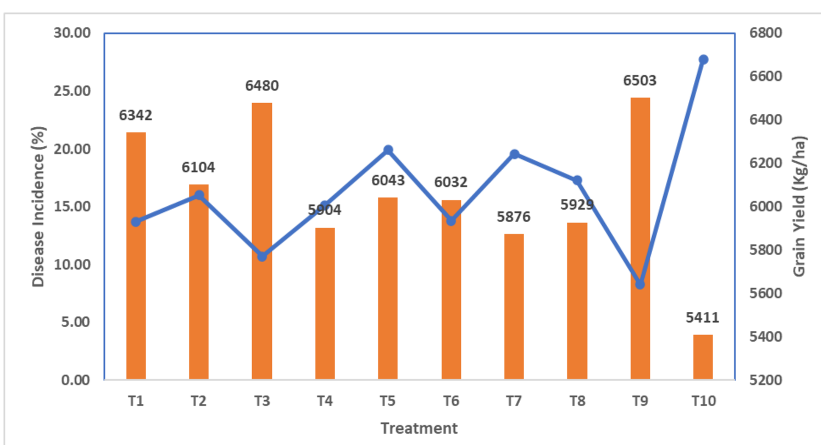

Figure 2: Graphic representation on the effect of different fungicides on false smut disease severity and grain yield

Table 1: Effect of fungicides on false smut disease incidence and severity along with grain yield at Kaul, Haryana

Treatments	Percentage of infected panicles			Percentage of infected spikelets			Grain yield (kg/ha)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T1 - azoxystrobin 25 SC	17.62 (24.74)	13.56 (21.56)	15.59 (23.15)	0.56 (0.74)	0.62 (0.79)	0.59 (0.77)	7233	7633	7433
T2 - difenoconazole 25 EC)	14.96 (22.68)	14.42 (22.29)	14.69 (22.48)	0.38 (0.62)	0.47 (0.69)	0.43 (0.65)	7300	7033	7167
T3 - azoxystrobin 18.2% + difenoconazole 11.4% w/w SC	9.08 (17.44)	13.49 (21.48)	11.29 (19.46)	0.29 (0.53)	0.37 (0.61)	0.33 (0.57)	7500	7333	7417
T4 - metiram 55% + pyraclostrobin 5% WG	20.73 (27.03)	11.69 (19.94)	16.21 (23.49)	0.72 (0.84)	0.57 (0.75)	0.64 (0.79)	6333	6967	6650
T5 - pencycuron 22.9%	18.57 (25.48)	17.83 (24.92)	18.20 (25.20)	0.57 (0.75)	0.62 (0.79)	0.60 (0.77)	7433	7167	7300
T6 - tebuconazole 250 EC	14.93 (22.69)	10.33 (18.69)	12.63 (20.70)	0.47 (0.69)	0.31 (0.56)	0.39 (0.62)	7033	7067	7050
T7 - thiafluzamide 24% SC	23.67 (29.08)	12.35 (20.46)	18.01 (24.77)	0.54 (0.73)	0.60 (0.78)	0.57 (0.75)	6667	7367	7017
T8 - flusilazole 25%+ carbendazim 12.5%	16.44 (23.82)	13.25 (21.26)	14.85 (22.54)	0.27 (0.52)	0.45 (0.67)	0.36 (0.59)	7267	7100	7183
T9 - propiconazole 25 EC	8.12 (16.49)	8.66 (16.95)	8.39 (16.73)	0.18 (0.43)	0.23 (0.48)	0.21 (0.45)	7567	7467	7517
T10 - Untreated control	26.23 (30.76)	21.2 (27.38)	23.72 (29.07)	1.02 1.01)	1.06 (1.03)	1.04 (1.02)	6367	6900	6633
Mean	24.02 (29.34)	21.49 (27.61)		0.69 (0.83)	0.71 (0.84)		7036	7203	
CV (%)			9.54			8.13			2.97
LSD (< 0.05) (Treatment)			2.61			0.07			254
LSD (< 0.05) (Year)			1.17			0.03			113
LSD (< 0.05) (Treatment x Year)			3.69			0.10			359

*Values in parenthesis represent angularly transformed values

Table 2: Effect of fungicides on false smut disease incidence and severity along with grain yield at Ludhiana, Punjab

Treatments	Percentage of infected panicles			Percentage of infected spikelets			Grain yield (kg/ha)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T1 – azoxystrobin 25 SC	13.60 (21.62)	10.05 (18.42)	11.83 (20.02)	4.07 (2.01)	1.01 (1.01)	2.54 (1.51)	5054	5445	5250
T2 – difenoconazole 25 EC)	20.50 (26.88)	14.09 (22.03)	17.30 (24.46)	5.93 (2.43)	1.57 (1.24)	3.75 (1.84)	4980	5102	5041
T3 – azoxystrobin 18.2 % + difenoconazole 11.4 % w/w SC	14.20 (22.12)	6.17 (14.33)	10.18 (18.23)	4.00 (2.00)	0.53 (0.73)	2.27 (1.36)	5172	5913	5542
T4 – metiram 55% + pyraclostrobin 5% WG	17.33 (24.56)	10.78 (19.13)	14.06 (21.85)	5.07 (2.25)	0.99 (0.99)	3.03 (1.62)	4910	5407	5158
T5 – pencycuron 22.9 %	24.13 (29.40)	19.16 (25.85)	21.65 (27.63)	5.93 (2.42)	2.03 (1.42)	3.98 (1.92)	4671	4900	4786

Treatments	Percentage of infected panicles			Percentage of infected spikelets			Grain yield (kg/ha)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
T6– tebuconazole 250 EC	22.00 (27.91)	7.98 (16.39)	14.99 (22.15)	7.40 (2.69)	0.69 (0.83)	4.05 (1.76)	4848	5180	5014
T7 – thiafluzamide 24 % SC	27.60 (31.67)	14.70 (22.37)	21.15 (27.02)	6.80 (2.60)	1.49 (1.21)	4.15 (1.91)	4538	4929	4734
T8 – flusilazole 25%+ carbendazim 12.5%	27.07 (31.32)	12.37 (20.55)	19.72 (25.94)	7.80 (2.78)	1.27 (1.12)	4.53 (1.95)	4437	4911	4674
T9 – propiconazole 25 EC	10.54 (18.92)	5.72 (13.74)	8.13 (16.33)	1.80 (1.34)	0.59 (0.75)	1.19 (1.04)	5285	5693	5489
T10 – Untreated control	32.74 (34.85)	30.80 (33.65)	31.77 (34.25)	11.80 (3.43)	4.59 (2.14)	8.19 (2.78)	4176	4199	4188
Mean	26.93 (31.25)	20.64 (27.01)		2.39 (1.55)	1.14 (1.07)		4807	5167	
CV (%)			7.65			12.52			3.97
LSD (< 0.05) (Treatment)			2.19			0.27			337
LSD (< 0.05) (Year)			0.98			0.12			106
LSD (< 0.05) (Treatment x Year)			3.1			0.38			238

*Values in parenthesis represent angularly transformed values.

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Effect of land use on plant nutrient availability and soil carbon sequestration of Mokonisa Machi Watershade, Dugda Dawa District of Southern Ethiopia

Tadele Geneti[1], Haile Tamiru[2], Vijay Singh[3*] and Nuguse Godana[4]

Department of Plant Science, College of Agricultural Science, Bule Hora University, Ethiopia
[1]Lecturer & Head, Department of Plant Science,
[2]Lecturer (Agril. Economics),
[3]Associate Dean (Plant Science Research Affairs) and Professor,
[4]Dean (College of Agricultural Science)
*Email: vijaysingh1946@gmail.com

Abstract

Different land use practices have a varied impact on soil degradation as reflected by physical and chemical properties as well as soil carbon sequestration capacity. Meager studies have examined the effects of land use on plant nutrient availability and soil carbon sequestration in Ethiopia. Therefore, the present study was conducted to investigate the effects of land use on plant nutrient availability and soil carbon sequestration in Mokonisa Machi Watershade (10 km away from Bule Hora University), Dugda Dawa District of Ethiopia. Our study specifically found the differences between three different land use types on soil texture, soil pH, cation exchange capacity, organic carbon, total nitrogen, available phosphorus, exchangeable potassium and the implication of the farming practices on soil carbon sequestration. Soil samples were collected from 0-15 and 15-30 cm layer of forest land, cultivated land and grazing land. The soil texture belonged to mainly clay and heavy clay textural class. Along with soil depths, the bulk density showed an increasing trend from 1.12 to 1.27g/cm in all sampling sites. While decreasing trends were recorded in soil organic carbon, organic matter, cation exchange capacity, % total nitrogen, available phosphorous and exchangeable potassium. Marginal increase in pH was recorded with increase in soil depths of all land use systems. The average total soil organic carbon sequestration in forest, grazing and farm land was recorded was 95.2, 88.45 and 65.5 t/ha, respectively for surface soil, while 93.3, 73.75 and 62.5 t/ha, respectively for sub-surface soil. Thus, plant nutrient and soil fertility improvement are the most important management interventions to increase the soil productivity and production capacity of agricultural crops. Therefore, stakeholders should focus on management activities that improve the plant nutrient and bulk density to boost carbon sequestration capacity of the soil.

Keywords: Bule Hora University, Dugda Dawa District, Ethiopia, land use, Mokonisa Machi Water- shade, plant nutrient, soil carbon sequestration, soil depth.

Introduction

Forest cover of the Ethiopian highlands as a whole has reduced from 46% in 1950's to 2.7% of the land in the late 1980's (Anonymous, 2004). Though the forest resource is very limited, its demand remains high. According to the Ethiopian Forestry Action Program 1994, the national demand for woody biomass was estimated at 50 million m^3. Of which 90% is in the form of fuel wood. The supply was estimated to be only 14.4 million m^3, indicating a deficit of some 35.6 million m^3 or 71% of the demand (Anonymous, 2001). Different forest biomes have differed in soil organic carbon/soil organic matter storage capacity and soil is the largest terrestrial pool of organic carbon (Lal, 2004). In total, soil contains about 3 times more carbon than the atmosphere and 4.5 times more than in living organisms (Jobbagy and Jackson, 2000). Due to relatively large size and long residence time of carbon in soil, soils are potentially important natural sink for carbon (Barua and Haque, 2013).

Soil management practices play a significant role in sustainable agriculture and environmental quality. Land controlling practices have larger consequence on the course and degree of alterations in soil properties. Conversions of an area from native ecosystem to cultivated land may be the reason of soil quality degradation. Soil management practices such as soil tillage, fertilizers and extreme irrigation often create unsuitable changes in soil quality (Dunjo *et al*., 2003). Rapid population growth and long history of sedentary agriculture has changed the land use/ land cover system and has been a major cause of environmental degradation on most parts of the world including Ethiopia (Feoli *et al.*, 2002). In Ethiopia, where agriculture is the back bone of the economy; approximately 50% of GDP and 90% of foreign exchange earnings (Anonymous, 2002), it was estimated that half of the Ethiopian highlands *i.e.,* arable lands are moderately to severely degraded and nutritionally depleted due to over cultivation, over grazing, primitive production techniques and over dependent on rainfall (Hugo *et al.*, 2002). Agricultural activities change the soil chemical, physical, biological properties and play the major role for soil degradation primarily due to soil fertility decline as a result of absence of nutrient inputs (Alfred and Tom, 2008).

Hence, soil fertility depletion is considered as the fundamental biophysical causes for declining per capita food production in sub-Saharan African countries in general (Sanchez *et al*., 1997) and particularly in Ethiopia. The problems of land degradation and low agricultural productivity in the country resulting in food insecurity and poverty are particularly severe in the rural highlands (Hagos, 2003; Nedessa *et al*., 2005). Soil losses from crop and grazing lands have been reported as 42 and 5 tons/ha/year, respectively (Kassa *et al*., 2002; Bojo and Casells, 1995). The severity of land degradation in some parts of highlands is estimated to reach as high as to offset the gains from technical change. Finding solutions to these problems require identifying the suitable farming system, the environment and understanding the society (Anonymous, 2008). Despite climate and geological history which affects soil properties on regional and continental scales, land use and its management practices may be the dominant factors affecting soil properties and plant nutrient under small catchment scale. Land use and soil management practices affect the soil nutrients and related soil processes, such as erosion, oxidation, mineralization and leaching, *etc.* As a result, it can modify the processes of transport and re-distribution of nutrients. In non-cultivated land, the type of vegetative cover is a factor influencing the soil organic carbon content. Moreover, soils through land use change also produce considerable alterations and usually soil quality diminishes after the cultivation of previously untilled soils

Thus, the land use and type of vegetation must be taken into account when relating soil nutrients with environmental conditions. The particular nature of the typical rugged relief with slopes subjected to cultivation for many years in the study area had led to decline in soil fertility. Therefore, there is special need for the analyses of soil nutrients in relation to land use due to different land use practices have a varied influence on soil degradation on both physical and chemical properties of soil as well as on soil carbon sequestration capacity. Such a local analysis is necessary to estimate nutrient storage in semi-natural and cultivated ecosystems. Mengistu (2014) studied the effects of land use on plant nutrient availability and soil carbon sequestration in Ethiopia. Gebeyaw (2006) reported that increasing population pressure and shortage of land, deforestation and cultivation activities are being carried out on steep slopes, practice of fallowing and crop rotation being eliminated. Besides this, shortage of grasslands has forced the farmers to remove crop residues for animal feed and firewood rather than doing it as manure for maintenance of soil fertility and productivity. Therefore, the objective of the present study is to investigate the influence of different land use type and its management practices on plant nutrient availability and soil carbon sequestration of the soil in Dugda Dawa District of Ethiopia.

Materials and methods

Description of study area

Topography area of study site *i.e.,* in Dugda Dawa District and 10 km away from Bule Hora University, West Gujii zone, Oromiya Regional state of Ethiopia, is characterized by steep slope, gentle slope and flat slope. The steep slopes were dominated by forest whereas gentle and flat slopes are used for cultivation and grazing land. The dominant tree species such as *Podocarpus falcatus, Cupressus lusitanica, Juniperus procera, Olea africana, Cordia africana, Croton macrostachyus, Carissa edulis (*Agamsa), *Olea europe*, *Acacia albida*, *Acacia synchronica* (Wangayo*)* and others found in scattered manner are important for various socio-economic values of the local peoples. These people also cultivate main crops such as chat (leafy plant), Ensete (Ethiopian banana), coffee besides maize and wheat crops. The forest is mostly used for browsing, fire wood and also as sources of construction wood by the local people. The site area is found between $5^0$38 N and $38^0$14 E at elevation of 1825 m above mean sea level. The temperature of town is from 20°C to 25°C and receives mean annual rainfalls relatively not less than 700 mm with main rains in spring and small rain in autumn. Regarding the climate of the town, it is drying sub-humid (Anonymous, 2007).

Sampling method

Soil sampling sites were selected based on land use type of the landscape and vegetation types *i.e.,* tree, shrubs and herbs. The study area was divided into three sampling sites namely forest, cultivated and grazing land. Total 24 composite samples *i.e.,* eight composite samples per land use type of soil were collected from the surface (0-15 cm) and sub-surface soil (15-30 cm) by using an auger. Each composite sample was made from a pool of five samples. Before sampling, forest litter, grass and any other materials on the soil surface were removed. Every sampling point was Geo referenced and GPS readings of the coordinates system were taken from collected soil samples. In general, for the sake of simplicity a boundary for each composite sample location was made as below (Fig. 1).

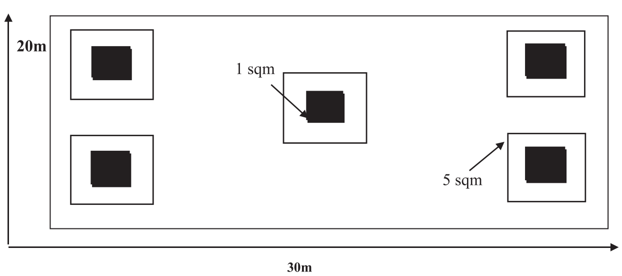

Figure 1. Boundary for each composite sample location

Soil sample preparation

Disturbed soil samples were collected from each site at the depth of 0-15 cm and 15-30 cm. Similarly, undisturbed soil samples were collected from each site at the respective depth for bulk density (BD) determination. The disturbed samples were air dried and crushed to pass through 2 mm sieve for determination of soil texture, CEC and pH. Sub-samples from each disturbed soil sample were ground to the size of 0.5 mm for the determination of soil organic carbon (OC), soil organic matter (OM) and total nitrogen contents. All the samples were made ready for the analysis of soil organic carbon sequestration.

Laboratory method

All soil samples were analyzed in Soil Testing Laboratory, Hawasa Institute using the following methods. Air dried soil was grounded with the help of pestle and mortal and then the soil was sieved through 2 mm sieve and only soil that passed through sieve was analyzed. Soil pH was measured potentiometrically in the supernatant suspension of 1:2.5 ratio of soil to a 1 ml KCl solution. CEC was determined by measuring the total amount of a given cation needed to replace all the cation from a soil exchange site and it is expressed in centimoles per 100 g soil (Cmol/100g soil). To do this, saturated sample was prepared followed by an extraction of the saturation cations adsorbed on the exchangeable complex and measuring its amount. Since CEC was highly affected by pH values, it was done at a known pH value and using ammonium acetate method.

Soil texture was determined by standard hydrometer method as described by Gee and Bauder (1986). BD of the soil was determined by the method of Blake and Hartage (1986). Titration method was followed to calculated percentage soil organic carbon (SOC). Soil organic matter (SOM) is oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid solution. A measured amount of $K_2Cr_2O_7$ was used in excess of the needed to destroy the SOM and the excess was determined by titration with ferrous sulfate solution, using diphenylamine indicator to detect the first appearance of un-oxidized ferrous iron. Total organic matter content of soil from OC measurements was estimated by the following equation.

$$\% \text{ SOM} = \% \text{ SOC} \times 1.78$$

The Kjeldahl procedure was used to calculate the percent total nitrogen. The basic principle is that the organic matter is oxidized treating soil with concentrated sulfuric acid, nitrogen in the organic nitrogenous compounds being converted into ammonium sulfate during the oxidation. The acid NH_4^+ ion in the soil was liberated by distilling with NaOH. The liberated NH_4^+ was absorbed by boric acid and back titrated with standard H_2SO_4. Potassium sulfate was added to raise the boiling point of the mixture during digestion and copper sulfate and selenium powder mixture are added as catalyst. The procedure determines all the soil nitrogen (including adsorbed NH_4^+) except that in nitrate form.

Available phosphorous content of the soil was determined by Olsen's method. The sample was extracted with sodium bicarbonate solution at pH 8.5. Phosphate in the extract was determined calorimetrically after treating it with ammonium molybdate sulfuric acid reagent with ascorbic acid as reducing agent. The high pH of the extracting solution renders the method suitable for calcareous, alkaline or neutral soils containing calcium phosphates because the Ca concentration in solution is suppressed by precipitation of $CaCO_3$, as a result the phosphate concentration in the solution will increase. Finally, exchangeable potassium and sodium were determined by flame photometric method. Total soil organic carbon (SOC) sequestration at the respective depths was calculated by the following equation.

Mass SOCS (t/ ha^{-1}) = OC x BD x D

Where:

OC = Organic Carbon Concentration (g C kg^{-1})

BD = Bulk Density of soil (g cm^{-3})

D = Depth (cm) of profile

Statistical Package for the Social Sciences (SPSS) version 20 was used to analyze soil data by descriptive procedures and a Pearson correlation matrix.

Results and discussion

Soil organic carbon

The recorded percent OC contents of the soils indicated a decrease with soil depth in all sample pit at all land use system (Table 1). Lower decrease in OC was recorded with depth in farm land than grazing and forest lands. Soil OC content for surface soil layer (0-15 cm) ranged from 4.25 to 2.66 %, while in sub-surface soil layer (15-30 cm) it varied from 3.92 to 2.46 % at the respective land use system. According to Walkley and Black (1934), soil OC content of the study area was in the medium to low range. It was higher in the surface layer of 0-15 cm than sub-surface layer of 15-30 cm. This might be due to higher clay content and rapid organic matter input. Similarly, Mehraj (2009) reported that the level of soil OC content was higher in the surface layer, dropping with an increase in soil depth. The reduction of soil OC content along depth could be linked to higher accumulation of plant debris and clay on surface than sub-surface layer of soil.

Organic Matter

The total soil OM in the study area at forest, grazing and farm lands was averaged to 4.03, 3.92 and 3.65 % at the depth of 0-30 cm, respectively (Table 1). However, the content of OM was higher in surface layer (4.75 to 3.79 %) than sub-surface layer (3.92-2.46%). With respect to land use system, there were slight differences in the percent OM content of the soil between forest and grazing lands, whereas drastic difference between forest and farm lands. High organic matter content at forest land may be due to dense vegetation coverage, vegetation type and litter input than other lands.

Total nitrogen

A decreasing trend in TN content was observed with soil depth in all sample pits at respective land use system (Table 1). This decrease in TN content could be due to decrease in soil organic carbon content with depths. Relatively, higher TN content in the surface of 0-15 cm is the result of accumulation of plant debris on the soil surface. Similar finding was reported by Yu and Jia (2014) that TN and SOC storage increased significantly with plantation age, but there were different changes as with soil depth. With respect to land use system, there were marginal differences in the percent total nitrogen content of the soil. However, the present study results showed slight change between forest and grazing land.

Soil reaction

Soil pH in the study area showed increasing trends with soil depth in all land use system. There were slight changes in the soil pH with soil depth at the respective land use (Table 1). Soil pH values at surface layer (0-15 cm) ranged from 5.95 to 6.90. According to Benton (2003), the soil pH for surface soil at all land use system was slightly acidic. The pH for sub-surface (15-30 cm) soil ranged from 6.01 to 6.92, which varied from neutral to slightly acidic reaction. Tegenu *et al.* (2008) reported that pH range of most productive soils is between 5.5 and 7.5.

Soil Cation Exchange capacity (CEC)

A decreasing trend of soil CEC with increasing soil depths in all sample pits at forest, grazing and farm land was noticed (Table 1). CEC in the surface layer of 0-15 cm was higher than sub-surface layer of 15-30 cm. The value of CEC in forest land as compared with grazing and farm lands. This may be due to availability of relatively higher OM content in the forest land than other two land use systems. The higher value of CEC in the surface layer in the study area might be due to higher decomposition of litter owing to favorable environment and higher organic matter input, which appears to be responsible to increase the value of CEC. Similar findings were reported by Foth (1990) and Brady and Weil (2002), who found that soils with large amounts of clay and OM has higher CEC than sandy soils with low OM. In surface horizons of forest soils, higher OM and clay contents significantly contributed to the CEC.

Bulk density (BD)

The BD showed an increasing trend with soil depth in case of forest and farm land (Table 1). Relatively, changes in BD values of soil with respective depth were higher in soils of forest land. The change or variation of BD in different land use and depth may be due to soil texture and organic matter in the study area. Lower BD recorded in the soils of surface layers (0-15 cm) as compared to sub surface layers (15-30 cm) might be due to higher OC contents. Similarly, Whalen *et al*. (2003) reported that soil bulk density declines with an increase in soil organic matter content of surface soil.

Exchangeable potassium (Ek)

Ek slightly decreased with the respective depth in all the three land use systems. But high average exchangeable potassium was found in the farm land as compared with other lands in the study area.

Available phosphorus (Ap)

The average total soil Ap was higher for farm land than forest and grazing land. Ap decreased with the respective depth in all land use systems. Ap content in the study area was 10.79-25.10 mg/100 g soil. According to Holford and Cullis (1985), available P of soil was high in this study area.

Soil particle size distribution

Relatively similar textural classes of the soils in different land use systems within soil depth of 0-15 cm and 15-30 cm was observed (Table 1). The textural class of surface and sub-surface soil (0-30 cm) in the study area was medium to heavy clay for all land use system. Most of the textural classes of soil in the study area were classified under heavy clay soil. The percentage of clay composition of soil was dominant as compared to silt and sand in the study area. This might be due to the degree of weathering, rainfall, parent material and the greater shielding effect of the canopy formed by the mature shrubs and understory vegetation from the erosive energy of the falling raindrops improve the texture of the soil. In line with this, Tegenu *et al*. (2008) reported that the composition percentage of clay was the highest for soils taken from shrub or bush followed by cultivated land. Similar finding was reported by Azlan *et al*. (2012), clay was the dominant soil particle in Pengkalan Chepa Industrial Park and southwest of Kota Bharu Township shrub and or forest soil. Sand contents showed increasing trends with soil depth. There were slight changes in the clay content of sample pits with a given soil depth at the respective altitudes.

Table 1: Soil testing laboratory analysis of respective land use types at various depths

Land type	Depth (cm)	OC (%)	OM (%)	TN (%)	SR (pH)	CEC	BD	Ek	Ap	TC	Sand	Clay	Silt
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Forest Land	0-15	4.25	4.75	0.20	6.12	10.40	1.12	0.43	11.22	Clay	6	76	18
	15-30	3.92	3.31	0.18	6.62	10.13	1.19	0.39	10.79	Clay	20	62	18
Grazing Land	0-15	3.51	4.48	0.17	5.95	8.31	1.26	0.28	18.12	Clay	52	36	12
	15-30	2.95	3.36	0.16	6.01	7.40	1.25	0.29	17.71	Clay	28	48	24
Farm Land	0-15	2.66	3.79	0.14	6.90	9.16	1.24	0.72	25.10	Clay	36	40	22
	15-30	2.46	3.52	0.12	6.92	9.37	1.27	0.67	24.48	Clay	18	64	18

OC= Organic Carbon, OM= Organic Matter, TN= Total Nitrogen, SR= Soil Reaction (pH), CEC= Cation Exchange Capacity (mg/100g soil), BD= Bulk Density, Ek= Exchangeable potassium (mg/100g soil), Ap= Available phosphorus (mg/100g soil), TC= Textural Class

Soil Organic Carbon Sequestration of different Land System

The total soil organic carbon sequestration (SOCS) recorded for forest land was 95.2 and 93.3 t/ha for the depths of 0-15 cm and 15-30 cm, respectively (Fig. 2). The average SOCS showed a slight decreasing trend in the forest land with soil depth. The grazing land showed 88.45 and 73.75 t/ha at soil depth of 0-15 cm and 15-30 cm, respectively. Among the three land use, the farm land showed the lowest values; 65.97 for surface layer of 0-15 cm and 62.5 t/ha for sub-surface layer 15-30 cm. In all land use systems, the average total SOCS was higher in the surface soil (0-15 cm) than in sub-surface soil (15-30 cm). This higher SOCS in the surface soil layer might be accounted for higher incorporation and decomposition of litter in under salutary environmental conditions. Similar trend was reported by Mehraj (2009) who found that *Pinus roxburghii* shrub/forest, where organic carbon was the highest in the surface layer (0-15 cm) as compared to its content in sub-surface layer (15–30 cm). In *Quercus leucotrichophora* shrub/ forest, the level of SOCS ranged from 24.3±1.9 g/kg^{-1} to 21.9±3.1 g/kg^{-1} and was higher in the surface layer, dropping with an increase in depth. Changes in the average SOCS with soil depth (1.9 t/ha) was the lower at the forest land relative to its changes *i.e.,* 14.7 and 3.47 t/ha with soil depth at grazing and farm land, respectively. There was drastic change in average SOCS between the two depths in the grazing land in the study area (Fig 2). This variation in average SOCS with depth is due to texture of soil and vegetation type/cover that affect organic carbon content of the soil.

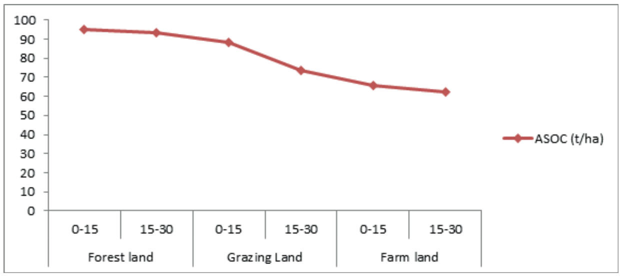

Figure 2. Soil organic carbon sequestration against depth of land use system

The average total SOCS at forest land was the highest in the study area as compared to grazing and farm land (Fig 2). Lower SOCS at farm land and grazing land as compared to forest land in the study area might be due to decrease in total tree density and basal area, slope of the land, cutting of tree for construction material, and low litter input and decomposition due to unfavorable environmental condition.

The forest land is covered with vegetation of different species composition natural and manmade forest such as *Podocarpus falcatus, Cupressus lusitanica, Juniperus procera, Olea africana, Cordia africana, Croton macrostachyus* and *Carissa edulis (*Agamsa*)* were dominant while *Olea europe, Acacia albida, Acacia synchronika* (Wangayo)*, Eucalyptus falcata* (Baharzaf) and others are found in scattered manner and forest land is mostly used for browsing, fire wood and construction purpose. Forest land was under less human impact relative to other land use system. Thus, more SOCS at forest land might be due to dense canopy, high vegetation residues like litter drop, root exudates, root mortality which can be converted into SOCS through decomposition. Similar finding was reported by Mulugeta (2004) that soil organic carbon sequestration (SOCS) increased with density of trees per hectare and decreased with other anthropogenic activities. In addition, Amundson (2001) reported the greater SOCS is due to greater accumulation of plant litter (increased C inputs) which resulted in relatively higher soil organic matter. In the study area, the total SOCS of forest, grazing and farm land were 188.5, 162.2 and 128.47 t/ha, respectively to depth of 0-30 cm (Fig 3). There was drastic change in total soil organic carbon stock between the three land use systems.

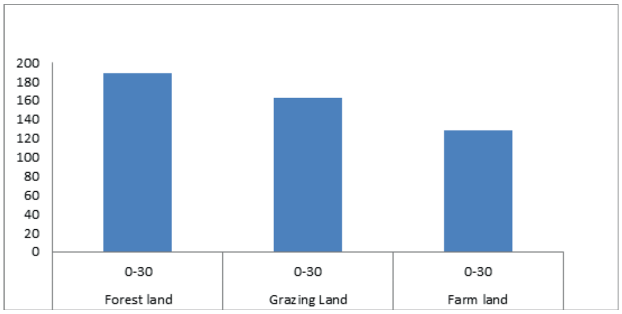

Figure 3. Total soil organic carbon sequestration along land use system (t/ha)

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