Efficacy of selected bio-pesticides and integrated management options in reducing *Liriomyza*(Diptera: Agromyzidae) infestations on basil (*Ocimumbasilicum* L.)

Alfayo Ombuya[1, 2], Dora Kilalo[2], Florence Olubayo[2], and Emmanuel Ariga[2]

[1]Kenya Plant Health Inspectorate Services, P.O Box 49592-00100, Nairobi, Kenya

[2]Department of Plant Science and Crop Protection, University of Nairobi P.O Box 30197-00100, Nairobi, Kenya

Correspondence: A. Ombuya, Department of Plant Science and Crop Protection, University of Nairobi, P.O. Box 30197-00100, Nairobi, Kenya

Abstract

The leaves of basil (Ocimumbasilicum) are used to add aroma and flavor to food in addition to their medicinal importance. The study aimed at evaluating the efficacy of neem and spinosadintegrated with yellow sticky traps and polythene mulch in the management ofLiriomyzaspp on basil. Eight options for management compared with the untreated control were tested to evaluate their effectiveness in reducing the number of leaflets damaged and the number of Liriomyzalarvae hatched on the ovipositedleaflets. The two sets of data were obtained from three tagged plants randomly selected per treatment on a weekly basis. Analysis of variance using SAS version 9.4 was done and least significant difference ($LSD_{0.05}$) pair-wise comparisons at 5% significance used to compare treatments. The treatment comprising of neem alternated with spinosad sprayed weeklywith Polythene mulch andyellow sticky traps significantly ($P\leq0.05$) reduced the number of leaflets damaged andthe number of Liriomyza larvae hatched on the infected leaves. It was observed that the integrated application of neem,spinosad, polythene mulch and yellow sticky traps is efficacious in the management of Liriomyzasppand can be adopted as an option in addressing the phytosanitary incompliance observed, food safety, pest resistance and environmental concerns that occur with the use of conventional chemical pesticides.

Key words: Efficacy, bio-pesticides,Leafminer (*Liriomyza spp.)*, Basil(*Ocimum basilicum*).

1. Introduction

Basil production is constrained by a variety of insect pests including *Liriomyza spp.Liriomyza* affect the quality of leaves by direct feeding and by creating wounds that form entry points for disease causing pathogens.Besides feeding, adult females cause damage during oviposition (Parrellaet al., 1985). Larva is the most destructive stage causing mining of leaves. Presence of eggs, larvae, pupa or even adults in consignments during international trade is a major phytosanitary concern.

Various *Liriomyzaspp* management practices have been recommended by a range of authors. *Gitongaet al. (2010)* observed that farmers in Kenya mostly limited their approach for the control of *Liriomyza* to the application of insecticides which have lately become subjects of pesticide residues exceedance and pest resistance. Bio-pesticides are generally acceptable in organic farming due to their low toxicity (Sporleder and Lacey, 2013). Neem and spinosad incorporated in this research are bio-pesticides categorized as bio-chemical pesticides. Neem is documented to control over 400 species of insect pests including *Liriomyzaspp* (Schmutterer and Sing, 1995; Saxena, 1989). Besides, neem is recorded to exhibit extremely low mammalian toxicity (Champagne *et al*., 1989). Spinosad is a product of bacterial fermentation which kills through stomach poisoning and contact activity (Salgado, 1998).

When applied in mass trapping, yellow sticky traps effectively control *Liriomyzaspp* at low densities. Yellow sticky traps are also applied in pest monitoring. In monitoring, they give an indication of the adult *Liriomyza* population trends to determine the timing of enhanced control measures. Aridaet al. (2013) depicted that when yellow sticky traps were applied in management of *L. trifolii*, the average number of mines per leaf were significantly lower in fields with yellow sticky traps after 50 days.

Reflective Polythene mulches have been shown to reduce certain insect pests and diseases on crops (Utah State University Extension, 2016; *Ngouajioet al. 2008*; Summers and Stapleton 2002). Fully grown *Liriomyza* larvae mostly exit host leaves and drop to the ground to pupate. Polythene mulch may not provide conducive environment for the pupae to molt. The pupae are exposed to desiccation and adverse temperatures resulting to death hence reducing the overall number of emerging adults.

There is scarce information in regard to the management of *Liriomyzaspp* using bio-pesticides integrated with sticky traps and polythene mulch on basil. This study was undertaken to determine the efficacy of the above approaches for *Liriomyza* management while addressing food safety concerns resulting from traditional pesticide use.

2. Materials and Methods

2.1. Location and description of the experimental site

This study was undertaken in the field station of the University of Nairobi College of Agriculture and Veterinary Sciences Kabete. It comprised of two seasons of three months each from late February to November 2016. Kabete lies at an altitude of 1900 m above the sea level (m.a.s.l) with average annual rainfall of 1,200 mm. The soils are volcanic well drained with moderate fertility suitable for tea, pyrethrum, coffee and horticultural production (*Jaetzoldet al., 2006*). Farmers in this locality mainly practice continuous cropping of various crops undertaken in separate rotation and commercial fields. Temperatures are generally warm with a mean of 22°C. The hot period range from January to March while July to August is the coldest period. Temperatures fall to 7°C during cold months and can rise up to 34°C during hot months. The average relative humidity ranges from 54% in dry months to about 100% during wet months (Jaetzold*et al*., 2006).

2.2 Establishment of crop and experimental layout

Before undertaking the study, a survey was conducted in five (5) large scale growers to establish the management practices applied on *Liriomyza*. The growers selected were based on volumes grown and the frequency of export to foreign markets. Across the farms, it was established that the companies commonly applied evisect® (thiocyclam- hydrogenoxalate) for *Liriomyza* management while yellow sticky traps were largely applied in pest monitoring.

Seedlings of Bonanza® variety were rooted on trays using coco peat media in a nursery. At the field, the experimental site was demarcated and the field was ploughed by a tractor and plots manually prepared by hoes. Each plot measured 2m by 2m. As part of the farmer practice, chicken manure was in cooperated in the soil at a rate of 5t/ha. Di-Ammonium Phosphate (DAP {18:46:0}) fertilizer was broadcasted at a rate of 50kg/acre before transplanting. Polythene mulch was locally purchased. It was cut into pieces enough to stretch over the selected 2M by 2M plots and secured by soil on the edges. Each plot consisted of 6 rows with a spacing of 30 cm between the rows and 20 cm between plants. A maximum population of 60 plants was raised per plot. On the plots bearing polythene mulch, hills were made on the polythene based on the required spacing to allow for planting and irrigation.

The experiment was set out in randomized complete block design in three replicates. The nine treatments comprised of: (i) Untreated Control (ii) Yellow sticky traps only (iii) Polythene mulch only (iv) Spinosad sprayed weekly with yellow sticky traps (v) Neem sprayed weekly with Yellow sticky traps (vi) Neem alternated with spinosad sprayed weekly with Yellow sticky traps (vii) Evisect® (Thiocyclam 50% w/w of thiocyclam- hydrogenoxalate) only sprayed weekly (viii) Polythene mulch with yellow sticky traps (ix) Neem alternated with Spinosad sprayed weekly with Polythene mulch and Sticky traps. The treatments were randomly allocated to the plots using random numbers that were generated using MS Excel 2010 between 1 and 9 per block.

A Commercial product Tracer® 480SC containing spinosad was applied. It is a suspension concentrate containing 480 g/litre (44.03% w/w) of spinosad applied at a rate of 0.2-0.5L/ha at intervals of 7-10 days with a pre-harvest interval of 10 days in most crops. Neem based product Nimbecidine was locally purchased. It is a liquid product containing Azadirachtin 0.03% applied at a rate of 50ml/20L or 2.5-3L/Ha at a pre-harvest interval of 7 days. Evisect® (Thiocyclam 50% w/w of thiocyclam-hydrogenoxalate) was also locally purchased. It was applied at the rate of 500-800g/ha or 7-10g/20L weekly with a pre-harvest interval of 7 days. Yellow sticky cards of sizes 25 by 10 cm were purchased locally. They were used as per the manufacturer's recommendation of 1 trap per 2 m^2. Spraying of pesticide treatments was done in the evening when winds were low. It was done using a hand sprayer while keeping in mind that good coverage of the crop by the applied products increased the efficacy of the active ingredients. Wind direction was also considered in avoiding contamination of neighbouring plots. Yellow sticky traps were monitored and changed weekly and were adjusted accordingly as the crop increased in height.

Two parameters were evaluated: the number of leaflets with *Liriomyza* damages and number of larvae on damaged leaves. The data was collected from the middle four rows of each plot weekly for a period of seven weeks. Three plants were randomly sampled and tagged weekly in each plot using random numbers generated through MS Excel 2010 between 1 and 40.

2.3 Sampling for Pesticides residue Analysis

At the fifth week during the first and second season, leaf samples were collected for pesticide residue analysis using the Codex Alimentarius guidelines on sampling for food safety. Nine samples of 1kg of fresh leaves were randomly collected representing each treatment. The samples were analyzed at the Analytical Chemistry Laboratory of the Kenya Plant Health Inspectorate Services.

2.4 Statistical Analysis

The data collected on the number of leaflets damaged by *Liriomyzaspp* and the number of larvae on damaged leaves were transformed (using the formula: square root + 1) and later subjected to the analysis of variance (ANOVA) using SAS version 9.4 to assess the effects of treatments on the quantity of damage and the number of larvae hatched after oviposition. Least significant difference (LSD)-Pair-wise comparisons was used to compare significant differences among treatment means ($P \leq 0.05$).

3. Results

3.1 Number of leaflets with *Liriomyza* damages

In season one, *Liriomyza* infested the crop naturally and the various treatments tested significantly ($P \leq 0.05$) reduced the number of leaflets damaged by *Liriomyza* compared to the untreated control. The untreated control registered the highest mean in the number of leaflets damaged and was significantly ($P \leq 0.05$) different from all the other treatments applied. The treatments comprising of yellow sticky traps only, polythene mulch only and Polythene mulch with Yellow sticky traps were not significantly ($P \leq 0.05$) different from each other. Evisect® only (farmer practice), Neem Weekly with Yellow sticky traps and Spinosad weekly with yellow sticky traps registered a lower mean on the number of leaflets damaged in that order and were not significantly different ($P \leq 0.05$) from each other. The treatment comprising of Neem with spinosad (alternated weekly) and yellow sticky traps was significantly ($P \leq 0.05$) different from Neem with Spinosad (alternated weekly) together with Polythene mulch and yellow sticky traps. The treatment comprising of Neem with Spinosad (alternated weekly) together with Polythene mulch and yellow sticky traps was significantly different from all the other treatments and it is the treatment that recorded the lowest mean number of damaged leaflets in the season (Table 1).

In season two, the infestation by *Liriomyzaalso* occurred naturally andthe various treatments tested significantly ($P \leq 0.05$) reduced the number of leaflets damaged *Liriomyza* compared to the untreated control. The untreated control was significantly ($P \leq 0.05$) different from all the other treatments applied. Yellow sticky traps only, polythene mulch only and Polythene mulch with Yellow sticky traps treatments were not significantly ($P \leq 0.05$) different from each other. Evisect® only (farmer practice), Neem Weekly and Yellow sticky traps, and Spinosad weekly and yellow sticky traps were not significantly different ($P \leq 0.05$) from each other. Neem with spinosad (alternated weekly) and yellow sticky traps was significantly ($P \leq 0.05$) different from Neem and Spinosad (alternated weekly) together with Polythene mulch and yellow sticky traps and the later recorded the lowest mean number of damaged leaflets in the season (Table 1).

3.2 Number of larvae on damaged leaves.

In the first season, the mean number of larvae observed on damaged leaves was highest in the untreated control and was significantly ($P \leq 0.05$) different from all the other treatments. The mean number of larvae observed on Yellow sticky traps only, was not significantly ($P \leq 0.05$) different from that observed on polythene mulch only. Polythene mulch with Yellow sticky traps on its own was significantly ($P \leq 0.05$) different from all other treatments but the fourth from the untreated control in terms of the mean number of larvae on damaged leaves. Evisect® only (farmer practice), Neem Weekly with Yellow sticky traps, Spinosad weekly with yellow sticky traps and Neem and spinosad (Alternated weekly) with sticky traps were not significantly ($P \leq 0.05$) different. Neem and Spinosad (alternated weekly) together Polythene mulch and yellow sticky traps had the least mean on the number of larvae on damaged leaves but was not significantly different ($P \leq 0.05$) from Neem Weekly with Yellow sticky traps, Spinosad weekly with yellow sticky traps, and Neem and spinosad (Alternated weekly) with sticky traps (Table 2).

In the second season, the treatments tested also significantly ($P \leq 0.05$) reduced the number of larvae observed on damaged leaves. The mean number of larvae in the untreated control and was significantly ($P \leq 0.05$) different from all the other treatments. The treatments comprising of Yellow sticky traps only, polythene mulch only and Polythene mulch with Yellow sticky traps were not significantly ($P \leq 0.05$) different from each other. Evisect® only (farmer practice) and Neem Weekly with Yellow sticky traps were not significantly ($P \leq 0.05$) different. Neem Weekly with Yellow sticky traps was not significantly different from Neem and spinosad (Alternated weekly) with sticky traps.Spinosad weekly with yellow sticky traps and Neem and Spinosad (alternated weekly) together with Polythene mulch and yellow Sticky traps were not significantly ($P \leq 0.05$) different though the later recorded the lowest mean on the number of larvae on damaged leaves (Table 2).

3.3 Maximum Residue levels

Fresh leaf samples were analyzed for pesticide maximum residue levels (Table 3 &4). In both seasons, no sample exceeded the maximum acceptable limit of 1mg/kg for Azadirachtin (Sum of AzadiractinA& B) analytes. In addition, no sample exceeded the acceptable limit of 15mg/kg for spinosad (Sum of spinosyn A and spinosyn D) analytes. The samples obtained from Evisect® (farmer practice) treatment tested positive for Thiocyclam-hydrogenoxalateat 0.401mg/kg in the season of March-June 2016 and 0.3652mg/kg in seasonJuly-September 2016. The two samples exceeded the World Trade Organization limit of 0.3mg/kg in cabbage (CODEX, 2010).

4. Discussion

The results showed that Neem alternated with spinosad integrated with polythene mulch and yellow sticky traps are effective for the control of *Liriomyza* on basil. The strategy reduced the adult damage on leaves in addition to reduction of the number of larvae hatched after oviposition. The reduction on damage and the drop on the number of larvae could be attributable to the individual complimentary or synergistic effects of each component of management incorporated.

Neem contributed to the results due to its anti-feedant, repellant and anti-molting properties (Vietmeyer, 1992) on the adults and the other growth stages of *Liriomyza*. In repelling the adults, punctures due to feeding and oviposition are greatly reduced. It is reported that neem works systemically and penetrates the leaf surface to act as an insect growth in-hibitor (Yildirim and Civelek, 2010). By inhibiting growth, damages due to larvae mining on the leaf surfaces are also deterred. In a study by Webb *et al*., (1983) water solutions of neem were found effective in killing both eggs and larvae of *Liriomyzasativae* on lima beans. Therefore, it is suggestive that some eggs and larvae might have been killed during the application of treatments. Neem injected into conifers and birch trees was also observed to significantly reduce *Liriomyza* infestation (Helson*et al*., 2001; Marion *et al*., 1990). In regard to other insect pests, Servicio de Sanidad Vegetal- Murcia (2008) in his study recommended the use of neem (Azadirachtin) as a preventive spray for the reduction of the infestation rates of *T. absoluta* larvae.

Spinosad has been applied in the control of caterpillar on fruits and vegetables. It has been found effective against thrips in tomatoes, peppers and ornamental plants. In addition, spinosad is effective on leafminers on vegetables and ornamental plants. The efficacy of spinosad on control of dipterous leafminers is recorded as equivalent to synthetic pyrethroids, most organophophates and carbamates (Bret *et al*., 1997). Through its contact activity, spinosad acts fast in killing the leaf miners. The larvae and adults upon contact cease from feeding, become paralyzed and die. As a result, the level of damage to the crop due to *Liriomyza* adults and the larvae is considerably reduced. Its activity on nicotinic acetylcholine receptors has been identified as the cause of death (Salgado, 1998). Due to the mode of action, spinosad is also recommended as a suitable tool for resistance management (Salgado, 1998).

Polythene mulches have been tested for insect control giving varying results. Reflective polythene mulch has been observed to reduce the population of thrips, aphids, spidermites and whiteflies on plants (*Gilreathet al., 2005).* The reflected light is thought to confuse the pests and is recorded as more effective than insecticides (Summers *et al*., 2002). During this study, it is suggestive that reflections from the polythene mulch might have contributed to the disruption of the *Liriomyza* from feeding and oviposition. The polythene mulch also changes the background from the brown colour of soil. That might have interfered with the migration and landing patterns of *Liriomyza* as it was observed on aphids by Prokopy and Owens (1983). The *Liriomyza* pupae mostly fall from the host plant leaves into the soil to pupate. With the polythene mulch underneath the plants, the pupae are exposed to desiccation and predators thus few adults that create damages emerge.

Sticky traps are hailed as an important component in an Integrated Pest Management (IPM) program. Yellow and blue sticky traps are applied in early detection of flying adult insect pests and management especially in green houses. They are more effective in early detection of infestations than intensive plant sampling. It has been scientifically proved that sticky traps reflect certain wavelengths which attract insects. Thrips for example detect and respond to UV light and colours using receptors (Norris *et al*., 2002). The yellow colour attracts a number of insect pests and the sticky substance applied on the material traps the insects. Traps that reflect the wavelengths of yellow are used in monitoring and management programs that include aphids, whiteflies and *Liriomyza spp***.** By trapping, the yellow sticky traps control target pest or at least slow their multiplication rates. Insects that do not fly like mites, mealybugs, scales, wingless aphids and immature stages of thrips and whiteflies will not be caught by the use of yellow sticky traps. Traps can be applied in insect pest management by mass trapping adults as a way to suppress target insect populations. According to Clare and William (2012) mass trapping of thrips (*F. occidentalis*) by use of blue sticky traps reduce the adult thrips per flower in semi-protected strawberry crops by 61%.

Integrated Pest Management (IPM) is a recommended technology to manage pests, reduce pesticide use and managing pesticide resistance. Application of neem, spinosad, polythene mulch and yellow sticky traps provides an IPM arrangement that is effective in pest management due to their different modes of action in killing *Liriomyzahence* the compliance to food safety limits. Neem and spinosad have been recommended in organic production (OMRI Products List, 2007; IFOAM guidelines, 2000) while polythene mulch and yellow sticky traps have zero risks on pesticide residue levels unlike Evisect® (Thiocyclam-hydrogenoxalate) that is commonly used by farmers of basil.

5. Conclusions and recommendations

The integrated management approach of utilizing neem, spinosad, polythene mulch and yellow sticky traps proved superior to the other options including farmer practice. The approach is sustainable in terms of pest management, pesticides use and management of pest resistance due to the use of pesticides. In the long term this approach is also cheaper due to the reduced risks of contamination by *Liriomyzaspp* that are reason for frequent interceptions in international markets for basil. As observed from the pesticides residue analysis, farmer practice when applied poses higher chances of interceptions due to exceedances in pesticide residues. Neem and spinosad due to quick degradation and non-mammalian toxicity are safer when incorporated in basil production (Niemann and Hilbig, 2000) compared to evisect® (thiocyclam hydrogen oxalate). They have a wide range of acceptable limits which reduces chances of detection. Repeated application of thiocyclam-hydrogenoxalate (Evisect®) creates auxiliary challenges of pest resistance making its usage environmentally unsafe.

Besides pest control, polythene mulch has a number of other benefits to the basil crop. Water deficit is among environmental stresses that affect agricultural productivity resulting to reduction in growth and yields. Use of polythene mulch is popular in vegetable production in conserving soil moisture (Anikwe*et al*., 2007). Polythene mulch increases soil temperature, control weeds, increases crop yields and leads to an efficient use of soil nutrients (Kumar and Lal, 2012; Hatami*et al*., 2012; Bhatt *et al*., 2011; Berihun, 2011; Mamkagh, 2009; Ban *et al*., 2009; Kwabiah, 2004). In this research, crops grown on polythene mulch were generally observed to be more vigorous, healthy, vegetative and taller; traits attributable to benefits of using polythene mulch.

The results of this study established that the integrated application of Neem, spinosad, polythene mulch and yellow sticky traps is efficacious in reducing leaf damage and the number *Liriomyzalarvae* on infested basil. The approach takes advantage of the different ways *Liriomyza* survives i.e. flight, feeding, oviposition and pupation in the ground. By using neem, spinosad, polythene mulch and yellow sticky traps, *Liriomyza* survival and multiplication is counteracted. Therefore, the approach forms a good IPM technology that is suitable for management of Liriomyza in compliance to phytosanitary standards, food safety concerns, pest resistance and environmental concerns. From another study conducted elsewhere, *Liriomyza* sets in quite early in a crop of basil. Therefore, growers could be advised to consider instituting monitoring measures at transplanting and to set in pest management strategies as soon asLiriomyza is observed.

References

Anikwe M.A.N., Mbah C.N., Ezeaku P.I &Onyia V.N. (2007). Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (Colocasiaesculenta) on an ultisol in Southeastern Nigeria. Soil Till.Res., 93 264-272 DOI:10.1016/J.still.2006.04.007.

Arida G.S., Punzal B.S., Shepard B.M. &Rajotte E.G. (2013). Sticky board traps for managing leafminer, Liriomyzatrifolii (Burgess) (Diptera: Agromyzidae), infestation in onion (Allium cepa Linn.). Philippine Entomologist, 27(2):109-119.

Ban D., Zanic K., Dumicic G.,Culjak T.G.,& Ban S.G. (2009). The type of polyethylene mulch impacts vegetative growth, yield and aphid populations in watermelon production. J. Food Agric. Environ., 7:543-550.

Bhatt L., Rana R., Uniyal S.P., & SinghV.P.(2011).Effect of mulch materials on vegetative characters, yield and economics of summer squash (*Cucurbita pepo*) under rainfed mid-hill condition of Uttarakhand.Veg. Sci., 38: 165-168.

Berihun, B. (2011). Effect of mulching and amount of water on the yield of tomato under drip irrigation. J. Hort. Forest., 3: 200-206.

Clare S*.,* &KirkW.(2012) Flower stage and position affect population estimates of the western flower thrips,*Frankliniellaoccidentalis*(Pergande), in strawberry,ActaPhytopathologica et EntomologicaHungarica*,* 47*, 1, 133*

Champagne D.E., Isman M.B., & Neil T. G. H. (1989).Insecticidal activity of phytochemicals and extracts of Miliacea (Arnason, J.T., Phiogene, B. J.R. and Morand, P. Eds., Insecticides of plant origin.A csSymp. Ser. 387 Washington, D.C.).

CODEX (2010). Codex alimentarius commission Pesticide residues in food and feed. Downloaded from http:// www.codexalimentarius.net/pestres/data/pesticides/index.html.Accessed on 31st May 2017.

Bret B.L. (1997). Biological properties of spinosad. Down to Earth 52:1: 6-13.

Jaetzold R., Schmidt H., Hornetz B.,&Shisanya C. (2006).Farm Management Handbook of Kenya, Vol. II/C1.Ministry of Agriculture, Kenya and German Agency Technical Cooperation team (CTZ), Nairobi.

Gilreath J., Santos P., Mirusso J., Noling J., &Gilreath P. (2005). Application Considerations for Successful Use of VIF and Metalized Mulches with Reduced Fumigant Rates in Tomato.UF/IFAS EDIS pub. HS 287, http://edis.ifas.ufl.edu/HS270. Accessed on 6th Jan. 2017

Gitonga Z. M., Okello J. J., Mithofer D., Chabi-Olaye A., &Ritho C. N. (2010). Control of invasive *Liriomyza*leafminers and compliance with food safety standards in Kenya's snow pea industry. J. Agric. Econ. 14: 2–4.

Hatami S., Nourjou A., Henareh M., &Pourakbar L. (2012). Comparison effects of different methods of black plastic mulching and planting patterns on weed control, water-use efficiency and yield in tomato crops. Int. J. Agric. Sci., 2: 928-934.

Helson B.V., Lyons D.B., Wanner K.W., Scarr T.A. (2001). Control of conifer defoliators with neem-based system bioinsecticides using a novel injection device. The Canadian Entomologist. 09. 133(5):729-744.

Kumar S.D. & Lal B.R. (2012). Effect of mulching on crop production under rainfed condition: A review.Int. J. Res. Chem. Environ., 2: 8-20.

Kwabiah A.B. (2004). Growth and yield of sweet corn (Zea mays L.) cultivars in response to planting date and plastic mulch in a short-season environment.Sci. Hort., 102: 147-166. DOI: 10.1016/j.scienta.2004.01.007

Mamkagh A.M.A. (2009). Effect of tillage time and black plastic mulch on growth and yield of Okra (*Abelmoschusesculentus*) growth under rain fed conditions. Int.J. Agric. Biol., 11:453-457.

Marion D.F., Larew H.G., Knodel J.J., Natoli W. (1990). Systemic Activity of Neem Extract Against the Birch Leafminer. Journal of Aboriculture.16:1 January.

Ngouajio M., Ernest J. (2008). Light transmission through colored polyethylene mulches affects weed populations. HortSci 39(6):1302– 1304

Niemann L., Hilbig V. (2000). Die gesundheitlicheBewertung des Einsatzes von NaturstoffenimPflanzenschutz am Beispiel von Neemkernextrakten. GesundePflanzen 52, 135–141.

Norris R.F., Caswell-Chen E.P., &Kogan M. (2002). Concepts of Intergrated Pest Management, pp: 376-7. Pretentic-Hall, India.

Parrella M.P, Jones V.P., Youngman R.R., &Lebeck L.M. (1985).Effect of leaf mining and leaf stippling of *Liriomyza spp*. on photosynthetic rates of chrysanthemum. Annals of the Entomological Society of America 78: 90-93.

ProkopyR.J.,& Owens E.D. (1983). Visual detection of plant herbivorous insects.Ann. Rev. Entomol. 28:337-364.

Salgado V.L. (1998). Studies on the mode of action of spinosad: Insect symptoms and

physiological correlates. Pestic.Biochem.Physiol. 60:1-102.

Saxena R.C. (1989). Insecticides from neem. In: Insecticides of Plant Origin Arnason. (Eds.): Philog`ene JT, Morand P, American Chemical Society Symposium Series 387, pp. 110-135.

Servicio de Sanidad Vegetal-Murcia.(2008). Control of *Tutaabsoluta* College of Agriculture Agua.

Schmutterer H., Singh R.P. (1995). List of insect pests susceptible to neem products. In: The Neem Tree, Azadirachtaindica A. Juss., and Other MeliaceousPlants:Sources of Unique Natural Products for Integrated Pest Management, Medicine, Industry and Other Purposes. (Ed.): Schmutterer H, Weinheim VCH, pp. 326-365

Sporleder M., Lacey L.A. (2013). Biopesticides. In: Giordanengo, P., Vincent, C., Alyokhin, A. (Eds.), Insect Pests of Potato: Global Perspectives on Biology and Management. Academic Press, Amsterdam. pp. 463-497.

Summers C.G., Stapleton J.J. (2002). Use of UV reflective mulch to delay the colonization and reduced the severity of *Bemisiaargentifolii* (Homoptera: Aleyrodidae) infestations in cucurbits. Crop Prot 21:921–928

Webb R.E., Hinebaugh M. A., Lindquist R. K.,& Jacobson M. (1983). Evaluation of Aqueous Solution of Neem Seed Extract Against*Liriomyzasativae* and *L. trifolii* (Diptera: Agromyzidae). Journal of Economic Entomology 03. 76(2):357-362.

Vietmeyer N.D. (1992). Neem: A tree for solving global problems. Report of an Adhoc panel of the Board of Science and Technology for International Development, Ed: National Research Council, Washington D.C. USA, National press, 141 pp.

Utah State University Extension.(2016). Use of Plastic Mulch for Vegetable Production.http://extension.usu.edu/files/publications/publication/Horticulture_Vegetables_2016-01pr.pdf. Accessed on 6th Jan. 2017

Yildirim E.M., Civelek H.S. (2010). Eff ects of diff erent insect growth regulators (IGR) on the vegetable leafminerLiriomyzasativae Blanchard (Diptera: Agromyzidae). Fresenius Environmental Bulletin Vol 19/No 11. p. 2562-2566.

Appendices

Table 1: Effect of treatments on the mean number of leaflets damaged by *Liriomyzaspp*

Treatment	**Season 1**	**Season 2**
Untreated control	3.21a	3.25a
Yellow sticky traps only	2.83b	2.95b
Polythene mulch only	2.80b	2.84b
Polythine mulch + Yellow sticky traps	2.63b	2.90b
Evisect® only sprayed weekly (farmer practice)	2.01c	1.98c
Neem Weekly + Yellow sticky traps	1.89cd	1.99c
Spinosad weekly + yellow sticky traps	1.87cd	1.91c
Neem + spinosad (Alternated weekly) + yellow sticky traps	1.79 d	1.62d
Neem + Spinosad (alternated weekly)+ Polythene mulch + yellow sticky traps	1.47e	1.46d

Transformation as square root (x + 1) used for analysis of data

Season 1 period from March-June 2016, F-Value= 68.06, P >0.0001 LSD (0.05) = 0.2025, CoeffVar= 14.56

Season 2 period from June-Sept. 2016, F-Value = 82.18, P >0.0001 LSD (0.05) = 0.2035, CoeffVar= 14.35

Means followed by the same letter in the column are not significantly different from each other.

Table 2: Effect of treatments on the mean number of larvae on damaged leaves

Treatment	Season 1	Season 2
Control	1.95532a	2.56365a
Yellow sticky traps only	1.68339b	2.28351b
Polythene mulch only	1.72154b	2.31360b
Polythene mulch + Yellow sticky traps	1.48350c	2.33524b
Evisect only sprayed weekly (farmer practice)	1.30081d	1.59097c
Neem Weekly + Yellow sticky traps	1.21834de	1.50184cd
Spinosad weekly + yellow sticky traps	1.13348de	1.22261ef
Neem + spinosad (Alternated weekly) + yellow sticky traps	1.19266de	1.33979ed
Neem + Spinosad (alternated weekly) + Polythene mulch + yellow sticky traps	1.07431e	1.14862f

Transformation as square root (x + 1) used for analysis of data

Season 1 period from March-June 2016, F-Value = 26.11, P <.0.0001 LSD (0.05) = 0.17, CoeffVar= 19.48

Season 2 period from June-Sept. 2016, F-Value = 88.75, P <.0.0001 LSD (0.05) = 0.17, CoeffVar= 14.92

Means followed by the same letter in the column are not significantly different from each other.

Table 3: Pesticide residue levels (mg/kg)for the crop harvested March-June 2016 season

Plot No.	Treatment type	Spinosyn A	Spinosyn D	Azadiractin A	Azadiractin B	Thiocyclam
18	Untreated control	0.00013	0.00078	0.0000	0.0004	0.0000
17	Yellow Sticky Traps only	0.0010	0.00021	0.0000	0.0000	0.0000
1	Neem alternated with Spinosad sprayed weekly + Polythene mulch + Sticky traps	0.387	0.471	0.0000	0.0191	0.0000
7	Neem alternated with spinosad sprayed weekly + Yellow sticky traps	0.309	0.216	0.0000	0.0000	0.0000
24	Polythene mulch only	0.0012	0.0000	0.0000	0.0000	0.0000
3	Spinosad sprayed weekly + yellow sticky traps	0.357	0.333	0.0000	0.0000	0.0000
23	Neem sprayed weekly + Yellow sticky traps	0.0030	0.00094	0.0040	0.04630	0.0000
21	Polythene mulch + yellow sticky traps	0.0012	0.00024	0.0000	0.0352	0.0000
19	Evisect® (Thiocyclam-hydrogenoxalate) only spayed weekly	0.0016	0.00072	0.0000	0.0000	0.4010

Table 4: Pesticide residue levels (mg/kg)for the crop harvested July-September 2016 season

Plot No.	Treatment type	Spinosyn A	Spinosyn D	Azadiractin A	Azadiractin B	Thiocyclam
13	Untreated control	0.0000	0.0000	0.0000	0.0000	0.0000
11	Yellow Sticky Traps only	0.0000	0.00001	0.0000	0.0000	0.0000
6	Neem alternated with Spinosad sprayed weekly + Polythene mulch + Sticky traps	0.1652	0.3213	0.0000	0.01871	0.0000
21	Neem alternated with spinosad sprayed weekly + Yellow sticky traps	0.2301	0.1842	0.0000	0.05241	0.0000
16	Polythene mulch only	0.0000	0.0000	0.0000	0.0000	0.0000
7	Spinosad sprayed weekly + yellow sticky traps	0.3274	0.2953	0.0000	0.0000	0.0000
27	Neem sprayed weekly + Yellow sticky traps	0.0000	0.00000	0.0248	0.06820	0.0000
8	Polythene mulch + yellow sticky traps	0.0000	0.00000	0.0000	0.0000	0.0000
1	Evisect® (Thiocyclam-hydrogenoxalate) only spayed weekly	0.0000	0.00000	0.0000	0.0000	0.3652