FARMERS' PESTICIDE USE PRACTICES AND PERCEPTION ON INSECT POLLINATORS AND POLLINATION IN TAITA HILLS, KENYA

Duncan K. Mwinzi[1], John H. Nderitu[1], John W. Kimenju[1] and Esther N. Kioko[2]
[1]*Department of Plant Science and Crop Protection, University of Nairobi, P.O. Box 30197-00100, Nairobi Kenya*
[2]*Zoology Department, National Museums of Kenya, P.O. Box 40658- 00100, Nairobi, Kenya*

Abstract

Chemical pesticides are commonly used in control in pests and diseases but often at the expense of environment and biodiversity. Chemical use poses a threat to insect pollinators, which help in enhancing the quality and quantity of agricultural produce. Farmers' perception on insect pollinators may have influence on how they conserve them. The objective of this study was to determine farmers' pesticide use practices and their perception on insect pollinators. A survey was conducted in farming villages surrounding Ngangao Forest, Taita Hills between March and April 2018. Seventy farmers were randomly sampled within ten farming villages and a structured questionnaire administered to them. Data was entered and analyzed using SPSS version 22.It was found that 29 chemical pesticide active ingredients belonging to 14 chemical groups were used against different pests and diseases in the area. The most commonly used chemical groups were synthetic pyrethroids and organophosphate with 49.2% and 20.7% frequencies, respectively. Over 80% of the farmers followed the recommended rates of chemical application as stated on the label. Farmers dispose used chemical pesticide containers in three main ways; burning 47.1%, burying 24.3%, in pit latrine 15.7% with few farmers disposing them in dustbin, leaving them in the field or disposing in nearby bushes. Majority of the farmers 90% know about beneficial insects including insect pollinators. More than half of the farmers 62.9% were aware that insect pollinators are important in agriculture enhancing fruit, seed and pod set. Hence, there is need for adoption of ecofriendly pesticides by farmers to conserve pollinators. In addition, there is need for awareness creation on conservation of insect pollinators through integrated pest and pollinator management strategies (IPPM) and management of pollinator habitat.

Keywords: Insect pollinators, Farmers perception, Pesticides, Pollinator Conservation, Taita Hills

Introduction

Pollinating insects have been undergoing a decline in abundance, occurrence, and diversity in many parts of the world (Ollerton *et al*., 2014; Potts *et al*., 2016). The decline in pollinators is of much concern because it represents a critical ecosystem service (Garibaldi *et al*., 2013). Loss of both wild and managed pollinators may negatively affect food production as many crop types rely, at least to some extent, on pollination for the quantity and/or quality of their yield (Klein *et al*., 2007; Aizen *et al*., 2009). The decline in pollinators is alarming that it raises questions regarding food security and stability of ecosystems functions (Potts *et al*., 2010). Assessment of insect pollinators at national and regional levels show high levels of threat mainly for bees and butterflies (Van Sway *et al*., 2010).

Several anthropogenic drivers are threatening the abundance, diversity and health of wild and managed pollinators, and the pollination services they provide to wild plants and crop (Vanbergen, & Insect Pollinators Initiative, 2013). The drivers for the decline in insect pollinators worldwide include habitat transformation or fragmentation (Kennedy *et al*., 2013), loss of diversity and abundance of floral resources (Kremen *et al.,* 2007), inappropriate use of pesticides (Pettis *et al.,* 2013) and climate change (Schweiger *et al.,* 2010).

The risk to pollinators from pesticides arises through a combination of toxicity and the level of exposure (Potts *et al.,* 2016). The magnitude of risk of pollinators from pesticides depends on chemical compounds used and scale of land management. Under controlled environments, pesticides like neonicotinoid exhibit a broad range of lethal and sublethal effects on insect pollinators (van der Sluijs *et al.,* 2015; Godfray *et al.,* 2015). Depending on the concentration of pesticides exposed to pollinators, pesticides may reduce pollination service provided by the pollinators (Stanley et al., 2015). According to Rundlöf *et al.* (2015) actual field exposure of wild pollinators to a neonicotinoid resulted to their reduced survival and reproduction.

Pollinators exposure to pesticides can be lessened through various methods including adoption of alternative forms to pest control, reduction in chemical pesticide use and adopting pesticide application practices which safeguard pollinators (Johansen *et al.,* 2013). Integrated pest management practices can also help in minimizing pesticide exposure (Ekström & Ekbom, 2011). Training of farmers on safe use of pesticides and reduction of pesticide use in agricultural setting can protect the pollinators from pesticide exposure (Waddington *et al.,* 2014).

Despite the important role of insect pollinators in agricultural production and the continued use of pesticides by small-scale farmers, there is inadequate information on farmers' pesticide use practices, which might pose a threat to the pollinators. There is also limited information on farmers' perception on insect pollinators and pollination services. The objective of this study was to determine farmer' pesticide use practices and their perception on insect pollinators and pollination service in Taita Hills.

Materials and Methods

Description of the Study Site

The study was conducted in Taita Hills, in farming villages adjacent to Ngangao Forest. The forest is an indigenous cloud forest within Taita Hills which is placed 03025'S, 38020'E.). The forest supports high diversity of pollinators that provide pollination service in the farmlands. It lies 10 Km from Wundanyi town with an altitude ranging from 1700 m to 1900 m a.s.l. The study area has two distinct rain seasons, short rain season and long rain season (Odanga, 2017). The mean annual rainfall in Taita Hills is about 1500ml and the mean temperature is 25^0C. The forest is surrounded by small-scale farms where intensive cultivation is practiced. Both rain fed agriculture and small-scale irrigation are carried out. The neighboring farms receive ecosystem services provided by the forest like pollination service. Farmers were sampled from a total of 10 villages that surround Ngangao Forest. The farmers' population in all villages is approximately the same. Sampled villages include; Maghimbinyi, Kimanghachugu, Marumange, Kishenyi, Mashighi, Matasenyi, Mraru, Mchonyi, Kitumbi and Kichi-Kirema (Figure 1).

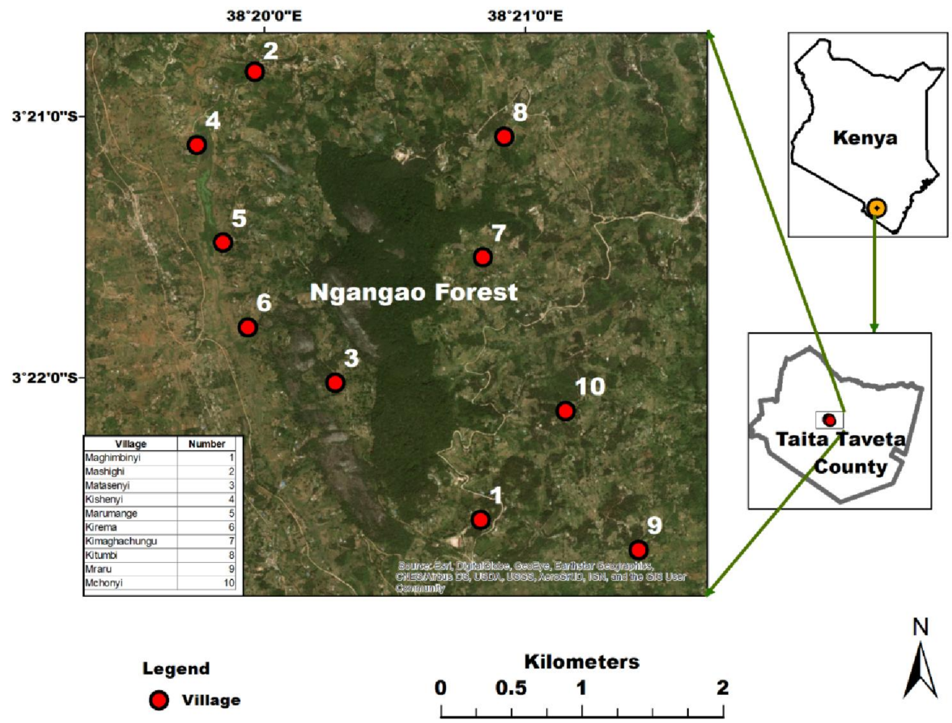

Figure 1 Sampled villages adjacent to Ngangao Forest, Taita Hills (Developed using ArcGIS, ILRI database)

Sampling and Data Collection

Data was collected in March and April 2018. The target group was farmers practicing crop farming, both rain fed or in irrigation set up in the villages adjacent to Ngangao forest. To test the validity and reliability of the information collected, the questionnaire was pre-tested with 10 farmers who were farmers in the study area and were not included in the main data collection survey. The pre-test further helped in refining the questions to ensure uniformity in understanding by all respondents. Seventy respondents (farmers) were determined using Single population Proportion Formula in the survey study area. A total of 10 villages adjacent to Ngangao forest were sampled and 7 farmers were randomly selected from each village. Farmer population in each village is approximately equal. The interviews were conducted face to face by the researcher and assisted by a member of the local community who had been trained on the concepts and contents of the questionnaire. The questionnaire was facilitated in both English and the local language. In each case, consent was first sought to participate in the survey from the respondents and then provided the explanation for the purpose of the survey which was to investigate farmers' pesticide practices and their perception on insect pollinators and pollination. After developing a rapport with the respondent, each interview took about 20 minutes to complete allowing ample time to express their true experience on chemical pesticide use practices, awareness on insect pollinators and pollinations services and conservation of insect pollinators.

Data Analysis

Data from the questionnaires filled during the interview were checked to ensure completeness, then coded and entered into spreadsheet using Statistical Package for Social Sciences (SPSS) software version 22. Descriptive statistics such as frequency distributions, means, and percentages were computed.

Results

Demographic Information

All the targeted farmers (70) responded to the structured questionnaires during the survey. Male respondents were dominant (82.9%; n=58). About 38.6% (n=27) of respondents were aged 35-45 years old followed by the age group 25-35 years with 28.6% (n=20). About 1.4% of the respondents were less than 25 years of age. Overall, the level of education was high with more than 50% having secondary and post-secondary education and only less than 3% had no formal education. The main occupation of the respondents was farming (92.9%; n=65) who inherited (81.4%) the land from the forefathers (Table 1). Land size in the study area is small scale. The average land size owned by the farmers is 1.84 acres (Standard deviation 1.4) while the maximum land size is 6.7 acres and the minimum at 0.25 acres.

Crops Grown by Farmers and their Pests

Farmers in Taita Hills carry out small-scale farming for subsistence use and for sale. The crops are grown in mixed farming systems. The common grown food crops in the area are 17 with Maize 80%, Kales 75.7%, cabbage 52.9 %, and common beans 50% as the commonly grown (Table 2). The average number of crops grown per farmer is six crops per season in the field mixed within the small pieces of land.

Different insect pests affect crops in Taita Hills. Based on the total farmer respondents (n=70), 92.5 % recorded that aphids are a major pest to their crops. Other insect pests encountered by farmers included whiteflies 80%, fall armyworm 64.3 %, cutworm 62.9 %, *Tuta absoluta* 32.9%, beetles 31.4%, and diamondback moth 25.7% (Table 3). Infestation of crops by insect pests in Taita Hills is a problem as all the respondents reported presence of insect pests in their farms. More than 90% of respondents observed insect pests attacking their crops more than once every crop season.

Table 1 Socio-demographic characteristics of surveyed farmers in Taita Hills

Variable	Frequency (No)	Frequency (%)
Gender		
Male	58	82.9
Female	12	17.1
Age		
Less 25 years	1	1.4
25-35 years	20	28.6
36-45 years	27	38.6
46-55 years	13	18.6
>55 years	9	12.9
Marital status		
Single	10	14.3
Married	58	82.9
Divorced	1	1.4
Widowed	1	1.4
Level of education		

No formal education	2	2.9
Primary education	32	45.7
Secondary education	31	44.3
Post-secondary education	5	7.1
Occupation		
Farming activities	65	92.9
Off farm activities	4	5.7
Business	1	1.4
Land ownership		
Purchased	6	8.6
Inheritance	57	81.4
Rented	7	10.0

Table 2 Crops grown by farmers adjacent to Ngangao forest, Taita Hills

Crop	Scientific name	Frequency (No)n=70	Frequency (%)
Maize	*Zea mays*	56	80
Kales	*Brassicae*	57	75.7
Cabbage	*Brassicae*	37	52.9
Common Beans	*Phaseolus vulgaris L.*	35	50
Tomatoes	*Solanum lycopersicum*	32	45.7
Spinach	*Spinacia oleracea*	29	41.4
French beans	*Phaseolus vulgaris*	27	38.6
Courgettes	*Cucurbita sp*	22	31.4
Lettuce	*Lactuca sativa*	15	21.4
Cucumber	*Cucumis sativus*	14	20
African Nightshade	*Solanum sp*	14	20
Potatoes	*Solanum tuberosum*	10	14.3
Chillies	*Capsicum sp*	9	12.9
Cauliflower	*Brassica sp*	8	11.4
Onions	*Allium cepa*	7	10
Snow Peas	*Pisum sativum*	7	10
Macadamia	*Macadamia integrifolia*	6	8.6

Table 3 Insect pests frequently observed by farmers infesting their crops

Pest	Frequency(No)	Frequency (%)
Aphids	65	92.5
Whiteflies	56	80
Fall Armyworm	45	64.3
Cutworm	44	62.9

Tuta Absoluta	23	32.9
Beetles	22	31.4
Diamondback moth	18	25.7
Grasshoppers	9	12.9
Spider mites	7	10
Leaf miners	4	5.7
Thrips	2	2.9

Chemical Use Practices by Farmers

All the farmers in Taita Hills use chemical pesticides to manage pests in their farms. Different chemicals in different chemical groups were used and at different rates. A total of 29 active ingredients were recorded belonging to 14 chemical groups were recorded. The chemicals recorded were of different WHO class. The highly common chemical active ingredients were Labda-Cyhalothrin (77.1%), Alpha-Cypermethrin (70%), Chloropyriphos 62.9% and Cypermethrin 62.9%. Synthetic pyrethroid and organophosphates were the highly used chemical groups. (Table 4).

WHO class II had the highest number of chemical groups and percentage usage by farmers with 19 chemical groups and 79.3 % usage by the farmers. WHO class I had two chemical groups with 6.3% usage, WHO class III had six chemical groups with 12.2% usage by farmers while WHO class U, had two chemical groups with 2.2% farmer usage (Figure 2)

Table 4 List of chemical active ingredients used by farmers with their chemical group, WHO class and percentage frequencies

S/N	Active ingredient	Chemical group	WHO class	% Frequency
1	LabdaCyhalothrin	Synthetic Pyrethroid	II	77.1
2	AlphaCypermethrin	Synthetic Pyrethroid	II	70
3	Chloropyriphos	Organophosphates	II	62.9
4	Cypermethrin	Synthetic Pyrethroid	II	62.9
5	Mancozeb	Dithio carbamate	III	31.4
6	Diazinon	Organophosphates	I	27.1
7	Emmamectin_Benzoate	Avermectin	II	25.7
8	Metalaxyl	Acylalamines	III	14.3
9	Flubendiamide	Flubediamide	II	11.4
10	Deltamethrin	Synthetic Pyrethroid	II	10
11	Propineb	Dithio carbamate	II	8.6
12	Abamectin	Avermectin	II	7.1
13	Azoxystrobin	methoxy-acrylates	II	5.7
14	Chlorantraniliprole	Chlorantraniliprole	U	5.7
15	Cymoxanil	cyanoacetamide-oxime	III	4.3
16	Oxymatrine	Oxymatrine	U	4.3
17	Thiamethoxam	Neonicotinoid	II	4.3
18	Acetamiprid	Neonicotinoid	II	2.9

19	BetaCyfluthrin	Synthetic Pyrethroid	II	2.9
20	Difenoconazole	Triazoles	II	2.9
21	Triadimefon	Triazoles	III	2.9
22	Carbendazim	Benzimidazoles	III	1.4
23	Ethoprophos	Organophosphates	II	1.4
24	Flusilazole	Triazoles	III	1.4
25	Lufenuron	Benzoylureas	II	1.4
26	Methomyl	Carbamates	I	1.4
27	Permethrin	Synthetic Pyrethroid	II	1.4
28	Triazophos	Organophosphates	II	1.4
29	Trichlorfon	Organophosphates	II	1.4

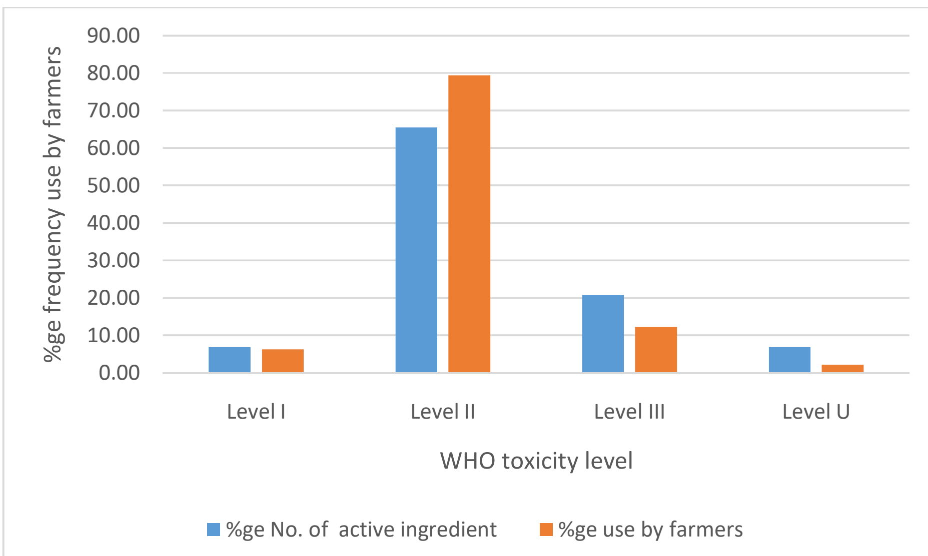

Figure 2 WHO classifications of chemicals pesticides used by farmers

The frequency of chemical pesticide use varied significantly among the respondents. More than 50% of farmers applied chemicals more than thrice in their crops per season. This significantly varied with the lower number (4%) of the farmers' who applied chemicals only once per season (Figure 3)

Most of the farmers spray chemicals early morning and late evening 81.4%, with 14.3% spraying anytime of the day while 4.3% of the farmers sprayed mid of the day. The weather condition at which the farmers spray chemicals mainly was when the weather is cold and calm 95.7%.

All the farmers sampled were in a position to get information on the recommended amount of chemical use. 80% of the farmers get the recommended rate of chemical use by reading from the labels (Figure 4)

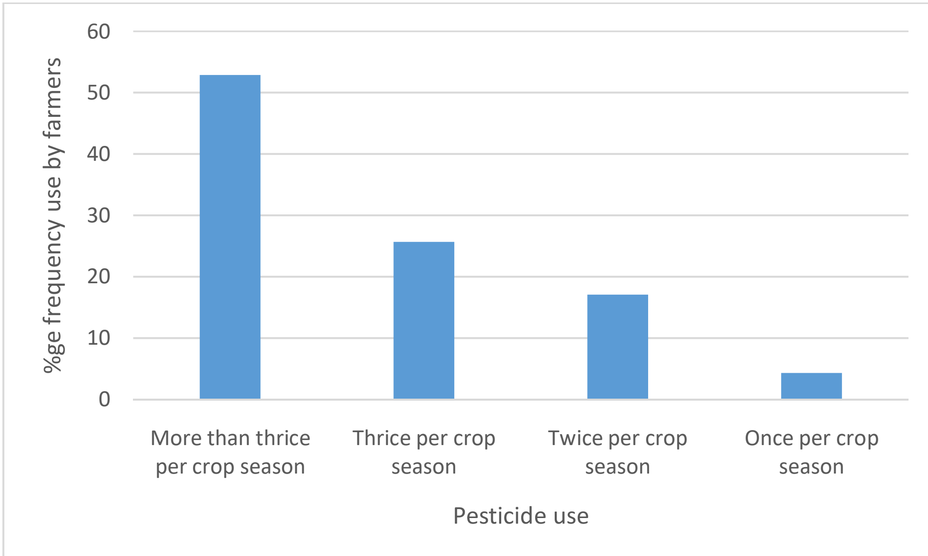

Figure 3 Frequency of chemical pesticides usage by farmers in a season

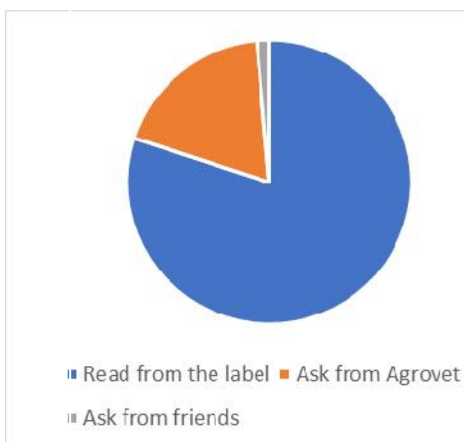

Figure 4 Ways in which farmers know the recommended rate for chemical pesticides application.

Farmers dispose used pesticide containers in different ways. The most commonly used method of disposal of used pesticide containers is through burning 47.1%. Other methods used by the farmers included burying (24.3%), throwing into pit latrines (15.7%), placing them in dustbins (5.7%), leaving in the farm (4.3%) and disposing them in the nearby bushes (2.9%) (Figure 5). More than half of the farmers surveyed were not trained on pesticide use (61.4%).

Farmers' Perception on Insect Pollinators and Pollination

More than 90% of the farmers in the research area were aware of beneficial insects and they were also aware of the effects of pesticides to beneficial insects (Figure 6). Similarly, farmers awareness on some of the beneficial insects are pollinators followed the same trend, with more than 90% of farmers in the study area being aware that some beneficial insects carry out pollination service (Figure 6).

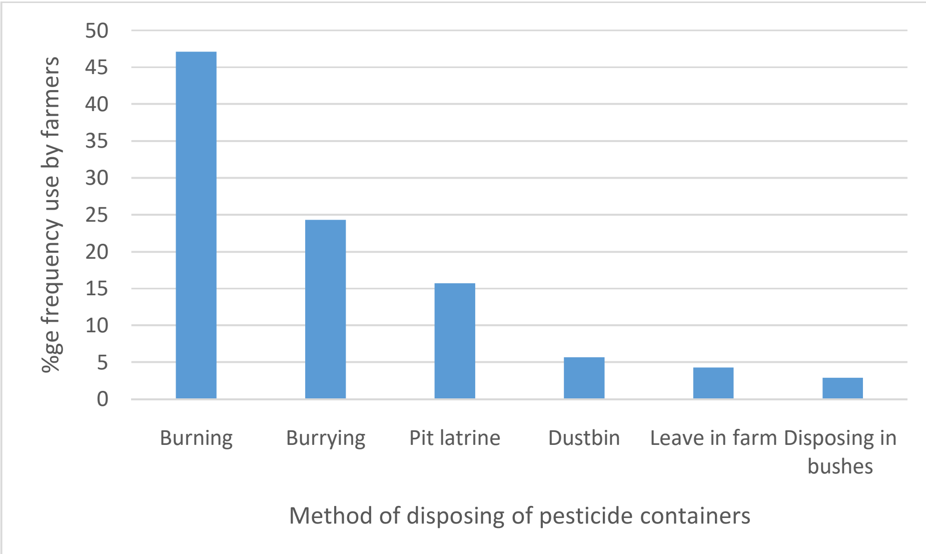

Figure 5 Methods of disposing of empty pesticide containers in Taita Hills

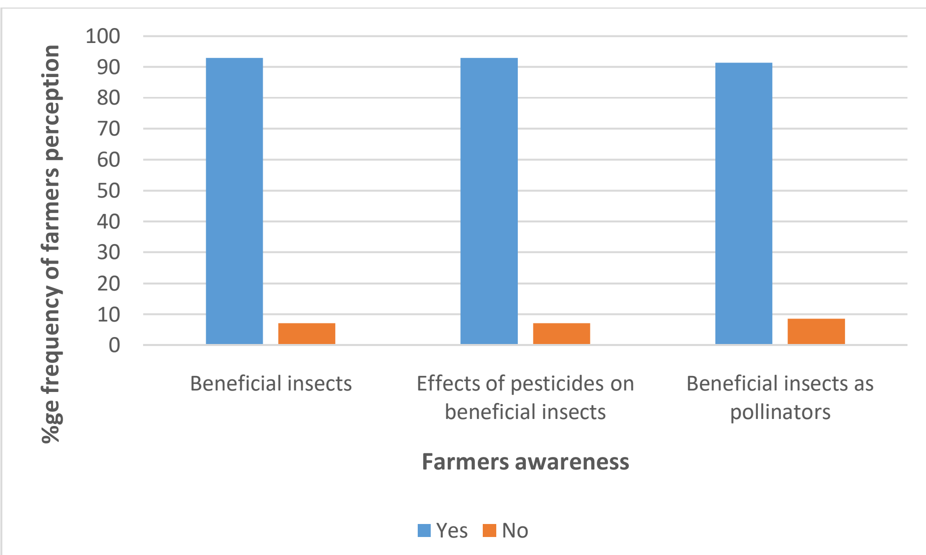

Figure 6 Farmers' awareness on beneficial insects, and the effects of pesticide use on beneficial insects

.

Farmers were aware that different insect visit flowers of different crops in their farms. The most common flower visitor observed by the farmers were the bees with 98.6% of the farmers observing bees visiting flowers in the field. Other flower visitors observed by farmers visiting their crops are butterflies (77.1%), Wasps (44.3%), ants (28.6%), Flies (20%), carpenter bees (5.7%) and ladybird (5.7%) (Figure 7).

The most visited crops by the insect flower visitors observed by the farmers were tomatoes (52.9%), beans (50%), Courgette (40%), French beans (37.7%), maize (28.6 %) Cucumber (25.7%) Potatoes (12.9%) and Capsicum (8.6%) (Figure 8).

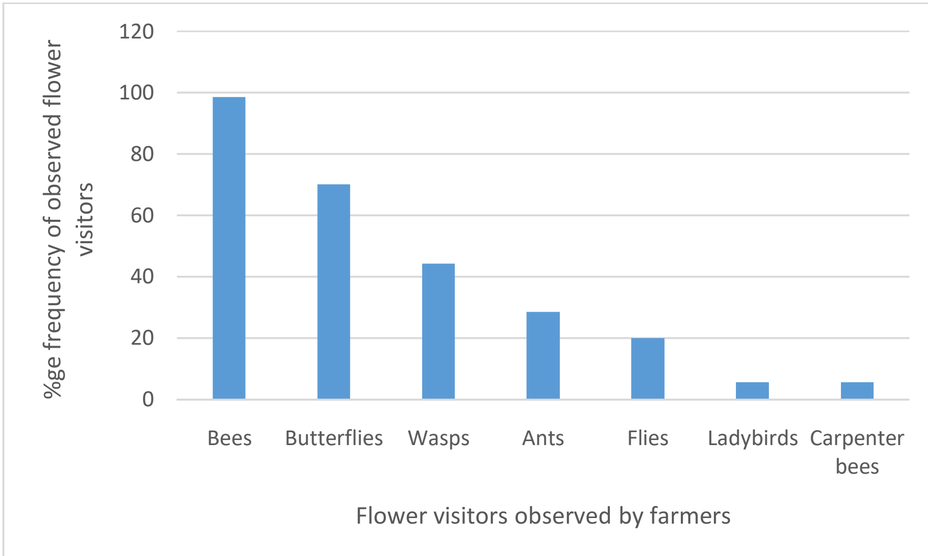

Figure 7 Insect flower visitors of the crops in the farmers' field as observed by farmers.

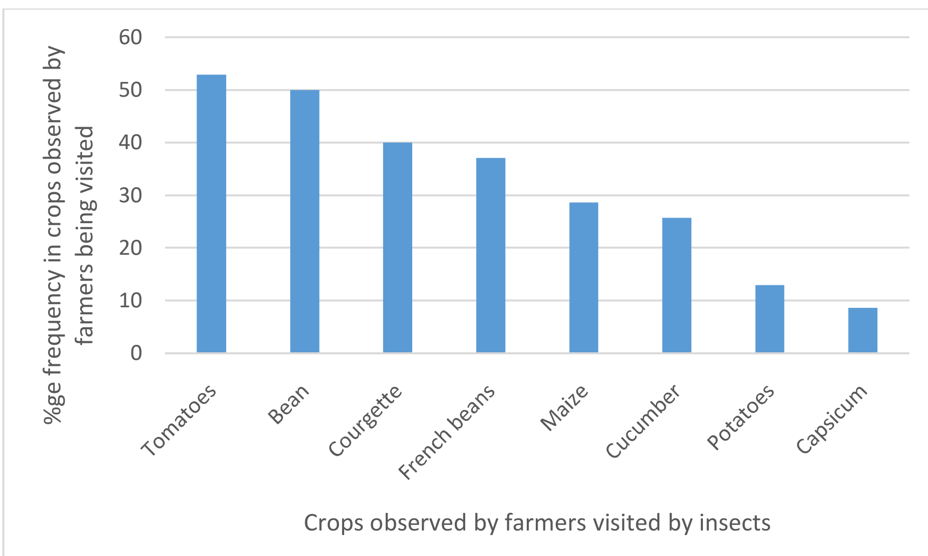

Figure 8 Crops mostly visited by insect flower visitors as observed by farmers

Farmers' in the study area were aware of the role of insect pollinators in agriculture. About 63% of the farmers were aware of the role of insect pollinators in agriculture. Thirty four percent were not sure whether insect pollinators have a role in agriculture and 2.9% of the farmers perceived that insect pollinators play no role in agriculture (Figure 13). Similarly, farmers' knowledge on contribution of insect pollinators in fruit, seed and pod set followed the same trade with 62.9% agreeing, 34.3% not sure and 2.9% disagreeing (Figure 9).

Conservation of Insect Pollinators by Farmers

Most farmers in the study area conserve and protect insect pollinators (84.3%, n=59) with a few farmers not conserving and protecting the pollinators (15.7%, n=11). The farmers use different methods in conservation and protection of pollinators by spraying chemicals early morning when pollinators are not foraging (84.7%), agricultural intensification (74.6%), managing pollinator habitat (28.8%) and use of alternatives to chemical pesticide such as natural pest control products, bio-pesticides and cultural control (25.4%) (Figure 10).

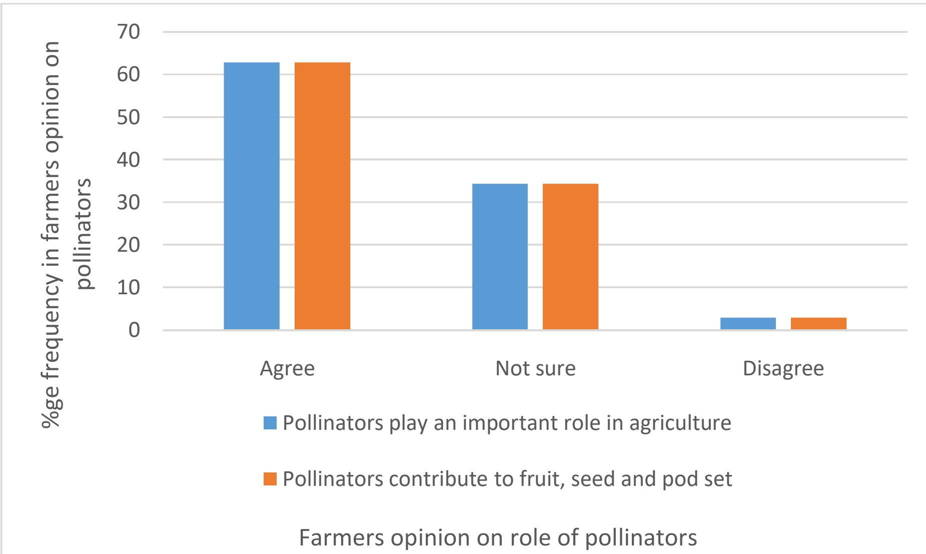

Figure 9 Farmers' knowledge on the role of pollinators in agriculture and insect pollinator contribution to fruit, seed and pod set.

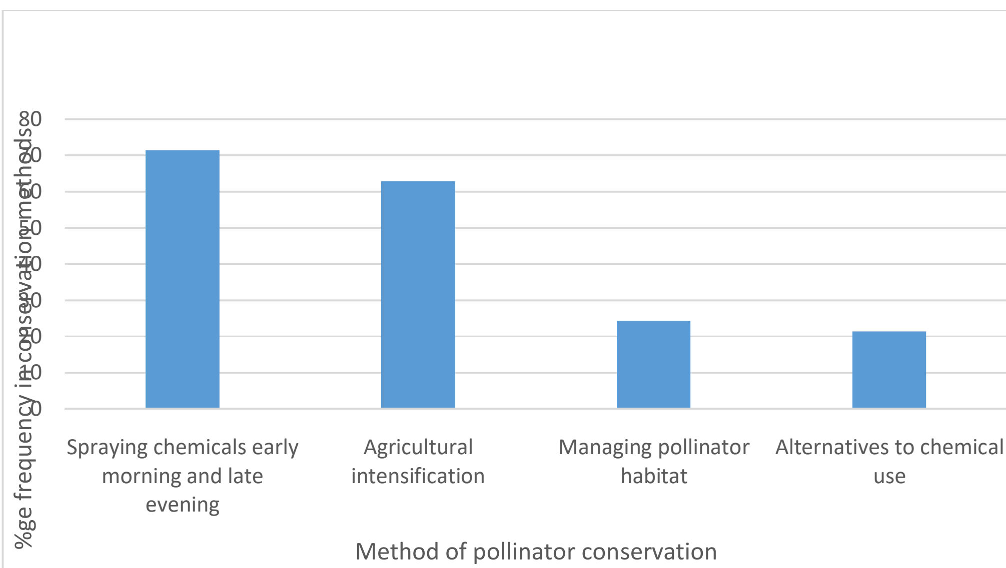

Figure 10 Methods used by farmers to conserve and protect insect pollinators

Discussion

Agriculture in Taita Hills is intensive small-scale subsistence farming. This is due to small pieces of land each farmer owns with the average land size owned by a farmer being 1.84 acres. This is in agreement with Maeda *et al*., (2010) on land use patterns in Taita Hills. The most commonly grown crops are maize, kales, cabbages and common beans. Agricultural intensification is highly carried out in Taita Hills with an average of six crops grown by each farmer per season. Horticultural crops are the main crops grown by the farmers as majority of the crops are vegetable crops. Insect pests are a major threat to farmers in the area. The major pests observed by farmers infesting their crops were aphids (*Aphidoidea*), whiteflies (*Aleyrodidae*), fall armyworm (*Spodoptera frugiperda*) and cutworms (*Agrotis sp*). Aphids (*Aphidoidea*), whiteflies (*Aleyrodidae*) are major pests of brassica family and are highly grown by the farmers (Flint, 2018). Fall armyworm is a current pest of maize and it has a widespread distribution within Kenya (Early *et al*., 2018).

Farmers in Taita Hills use chemical pesticides in management of pests that pose a threat to non-target organisms like pollinators and the environment. Twenty-nine active ingredients belonging to different chemical groups were recorded. The most common used chemical groups are synthetic pyrethroids, organophosphates, dithio carbamates and neonicotinoids. Synthetic pyrethroids exposure to bees has been demonstrated to have negative effects on their movement and interaction (Ingram *et al*., 2015). Neonicotinoid have been reported to pose an enormous threat to pollinators like bees (Stanley *et al*., 2015; Woodcock *et al*., 2017; Mitchell *et al*., 2017). These pesticides pose a threat to food security in the future due to reduction in insect pollinators that improve yield and quality of agricultural produce (Potts *et al*., 2010).

The pesticides used by the farmers belong to different WHO classes. The highest number of the pesticides belonged to WHO class II followed by WHO III class, with a few in class I and class U. Pesticides belonging to class I and II are likely to pose a health threat to the farmers and the environment inclusive of insect pollinators (Van Scoy *et al*., 2013). Some chemicals in class I and II have been classified as being extremely or highly hazardous in agricultural production and barred by some countries, but under use in developing countries (WHO 2003). The unrelenting use of the barred pesticides is due to pesticide corporations and dealers using trade negotiations to avoid the ban (Rosenthal, 2005). Class II pesticides are highly used by the farmers in the study area which might pose a threat to the environment and the pesticide users. There is low use of class U pesticides in the study area, which might be because of availability, cost and awareness creation for the products. Class U pesticides are known to be environmentally and user friendly compared to other chemical classes (Garcia *et al*., 2012). There is need for adoption of environmentally safe pesticides in order to protect beneficial insects including pollinators.

Farmers in the study area use high volumes of pesticides with the majority of them applying chemical pesticides more than three times in a cropping season. High pesticide loads are known to cause decline in pollinator diversity (Brittain *et al*., 2010). Time for chemical application is very important as it reduces insect pollinator exposure during foraging hours. Pesticide application early morning and late evening is encouraged as the pollinators and other beneficial arthropods are less active. Application of chemical pesticides during calm whether also reduces chemical drift to beneficial arthropods like pollinators and predators (Otto *et al*., 2009). Disposal of used pesticide containers is crucial in pollinator conservation. Farmers do not have good disposal systems for used pesticides containers hence chemical traces in the containers may end up into water bodies or be exposed to beneficial arthropods concurring with findings of Damalas *et al*. (2008). From the study, it was established that more than half of the farmers have not received any form of training of pesticide use. Training farmers on pesticide selection and safe use is key in environmental conservation (Damalas & Koutroubas, 2017).

Farmers' perception on insect pollinators and pollinations is crucial in conservation of insect pollinators. More than 90% of the farmers in the study were aware of beneficial insects, and insect pollinators contrary to findings of Misganaw *et al*. (2017) in Ethiopia where majority of respondents were not aware of pollination and importance of insect pollinators. Most of the respondents identified bees as the most common flower visitor and it concurs with Misganaw *et al*. (2017) that recorded bees as common flower visitor. Commonly visited crops by insects pollinators were tomatoes, beans and courgette. This implies that farmers are familiar with bee's dues to frequent visits to crops and other plants.

Above half of the respondents stated that they know the importance of insect pollinators in agriculture and their contribution to fruit, seed and pod set. This was contrary to Munyuli (2011) who reported that majority of the farmers surveyed in Central Uganda did not know the role played by honeybees in coffee yield increase. This may be due to a lot research done in the area over the last years in other fields aiming at conservation of the few indigenous forest fragments and probably there is no much research in Uganda on the same.

Majority of the respondents conserve and protect insect pollinators in their fields whereas few farmers' do not conserve and protect them. The farmers in their fields undertake different methods of conservation measures. Timing of chemical pesticide application, whereby farmers spray them early morning and late evening is the commonly used intervention to conserve the insect pollinators. This is because the pollinators are less active during early morning and late in the evening therefore reducing the chances of pesticide exposure. The respondents also do agricultural intensification as measure to enhance insect pollinator diversity. The average number of crops grown by each farmer is six crops; therefore, there are diverse floral resources for visitation by the insect pollinators (Tscharntke *et al*., 2012). Less than half of the farmers manage insect pollinator habitats. The pollinator habitat include fields planted with temporary flowering cover crops, field borders with perennial or annual flowering species, hedgerows comprising prolifically flowering shrubs and grass buffer strips. Managing pollinator habitat increases the ecological fitness of pollinator populations through enhanced larval and adult nutrition (Wratten *et al*., 2012). Use of alternatives to chemical pesticide use is least used by the farmers. This indicates there is over reliance of pesticides in the management of crop pests. There is need for farmer training to promote integrated pest and pollinator management (IPPM) strategies to reduce over reliance on chemical pesticides in the management of crop pests (Meissle *et al*., 2010).

Conclusion

Chemical pesticides are highly used by all farmers surveyed in the study. Farmers use different active ingredients belonging to different chemical groups with synthetic pyrethroid being the most commonly used chemical group. Farmer's disposal of empty pesticide containers may end up harming the environment. Few farmers have been trained on pesticide use in the study area. There is need for farmer training on best safe pesticides for use, which are environmentally friendly and safe use of the pesticides.

Most of the farmers are aware of beneficial insects and some beneficial insects are pollinators. Farmers observed honeybees as the most common flower visitor in their crops. Most of the farmers are aware of the role played by pollinators in agriculture but some of the farmers are not sure whether the insect pollinators are important in agriculture. Therefore, there is need for more farmer training on the role played by insect pollinators in agricultural production. Agricultural intensification and spraying chemicals early morning and late evening are the common methods used by farmers to conserve insect pollinators. There is need to create more awareness on the need to adopt other pollinator conservations methods like managing pollinator habitats and adopting chemical pesticide alternatives.

Acknowledgement
We are grateful to JRS Biodiversity Foundation for funding this study. We thank the National Museum of Kenya, Invertebrates Zoology section for facilitating the study. We wish to acknowledge the Taita Hills community for their support during the fieldwork.

References

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A., & Klein, A. M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of botany*, *103*(9), 1579-1588.

Brittain, C. A., Vighi, M., Bommarco, R., Settele, J., & Potts, S. G. (2010). Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic and Applied Ecology*, *11*(2), 106-115.

Damalas, C. A., & Koutroubas, S. D. (2017). Farmers' training on pesticide use is associated with elevated safety behavior. *Toxics*, *5*(3), 19.

Damalas, C. A., Telidis, G. K., & Thanos, S. D. (2008). Assessing farmers' practices on disposal of pesticide waste after use. *Science of the total environment*, *390*(2-3), 341-345.

Early, R., González-Moreno, P., Murphy, S. T., & Day, R. (2018). Forecasting the global extent of invasion of the cereal pest Spodoptera frugiperda, the fall armyworm. *bioRxiv*, 391847.

Ekström, G., & Ekbom, B. (2011). Pest control in agro-ecosystems: an ecological approach. *Critical Reviews in Plant Sciences*, *30*(1-2), 74-94.

Flint, M. L. (2018). Pests of the garden and small farm: a grower's guide to using less pesticide (Vol. 3332). *UCANR Publications*.

Garcia, F. P., Ascencio, S. Y. C., Oyarzun, J. G., Hernandez, A. C., & Alavarado, P. V. (2012). Pesticides: classification, uses and toxicity. Measures of exposure and genotoxic risks. *J. Res. Environ. Sci. Toxicol*, *1*(11), 279-293.

Garibaldi, L. A., Aizen, M. A., Klein, A. M., Cunningham, S. A., & Harder, L. D. (2011). Global growth and stability of agricultural yield decrease with pollinator dependence. *Proceedings of the National Academy of Sciences*, *108*(14), 5909-5914.

Garibaldi, L.A., Carvalheiro, L.G., Vaissière, B.E., Gemmill-Herren, B., Hipólito, J., Freitas, B.M., Ngo, H.T., Azzu, N., Sáez, A., Åström, J. & An, J., (2016). Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. *Science*, *351*(6271), 388-391.

Godfray, H.C.J., Blacquiere, T., Field, L.M., Hails, R.S., Potts, S.G., Raine, N.E., Vanbergen, A.J. & McLean, A.R. (2015). A restatement of recent advances in the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. *Proceedings of the Royal Society B: Biological Sciences*, *282*(1818), 20151821.

Ingram, E. M., Augustin, J., Ellis, M. D., & Siegfried, B. D. (2015). Evaluating sub-lethal effects of orchard-applied pyrethroids using video-tracking software to quantify honey bee behaviors. *Chemosphere*, *135*, 272-277.

Johansen, E., Hooven, L. A., & Sagili, R. R. (2013). How to reduce bee poisoning from pesticides.

Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society of London B: *Biological Sciences, 274*(1608), 303-313.

Kennedy, C.M., Lonsdorf, E., Neel, M.C., Williams, N.M., Ricketts, T.H., Winfree, R., Bommarco, R., Brittain, C., Burley, A.L., Cariveau, D. & Carvalheiro, L.G. (2013). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology letters*, *16*(5), 584-599.

Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, L., Potts, S.G., Roulston, T.A., Steffan-Dewenter, I. & Vázquez, D.P. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology letters*, *10*(4), 299-314.

Maeda, E. E., Pellikka, P. K., Siljander, M., & Clark, B. J. (2010). Potential impacts of agricultural expansion and climate change on soil erosion in the Eastern Arc Mountains of Kenya. *Geomorphology*, *123*(3-4), 279-289.

Meissle, M., Mouron, P., Musa, T., Bigler, F., Pons, X., Vasileiadis, V.P., Otto, S., Antichi, D., Kiss, J., Pálinkás, Z. & Dorner, Z. (2010). Pests, pesticide use and alternative options in European maize production: current status and future prospects. *Journal of Applied Entomology*, *134*(5), 357-375.

Misganaw, M., Mengesha, G., & Awas, T. (2017). Perception of Farmers on Importance of Insect Pollinators in Gozamin District of Amhara Region, Ethiopia. *Biodiversity Int J*, *1*(5), 00029.

Mitchell, E. A., Mulhauser, B., Mulot, M., Mutabazi, A., Glauser, G., & Aebi, A. (2017). A worldwide survey of neonicotinoids in honey. *Science*, *358*(6359), 109-111.

Munyuli, T. (2011). Farmers' perceptions of pollinators' importance in coffee production in Uganda. *Agricultural Sciences*, *2*(03), 318.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853.

Odanga, J. J. (2017) Climate change induced-effect on biology and ecology of avocado insect pests along altitudinal gradient of Taita Hills and Mount Kilimanjaro *(Doctoral dissertation, University of Nairobi)*.

Ollerton, J., Erenler, H., Edwards, M., & Crockett, R. (2014). Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. *Science*, *346*(6215), 1360-1362.

Otto, S., Lazzaro, L., Finizio, A., & Zanin, G. (2009). Estimating ecotoxicological effects of pesticide drift on nontarget arthropods in field hedgerows. *Environmental toxicology and chemistry*, *28*(4), 853-863.

Pettis, J. S., Lichtenberg, E. M., Andree, M., Stitzinger, J., & Rose, R. (2013). Crop pollination exposes honey bees to pesticides which alters their susceptibility to the gut pathogen Nosema ceranae. *PloS one*, *8*(7), e70182.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, *25*(6), 345-353.

Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J. & Vanbergen, A.J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, *540*(7632), 220.

Potts, S.G., Ngo, H.T., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J. & Vanbergen, A. (2016). The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production.

Rosenthal, E. (2005). Who's afraid of national laws?: Pesticide corporations use trade negotiations to avoid bans and undercut public health protections in Central America. *International Journal of Occupational and Environmental Health*, *11*(4), 437-443.

Rundlöf, M., Andersson, G.K., Bommarco, R., Fries, I., Hederströn, V., Herbertsson, L., Jonsson, O., Klatt, B.K., Pedersen, T.R., Yourstone, J. & Smith, H.G. (2015). Seed coating with a neonicotinoid insecticide negatively affects wild bees. *Nature*, *521*(7550), 77.

Schweiger, O., Biesmeijer, J.C., Bommarco, R., Hickler, T., Hulme, P.E., Klotz, S., Kühn, I., Moora, M., Nielsen, A., Ohlemüller, R. & Petanidou, T. (2010). Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. *Biological Reviews*, *85*(4), 777-795.

Stanley, D. A., Garratt, M. P., Wickens, J. B., Wickens, V. J., Potts, S. G., & Raine, N. E. (2015). Neonicotinoid pesticide exposure impairs crop pollination services provided by bumblebees. *Nature*, *528*(7583), 548.

Tscharntke, T., Clough, Y., Wanger, T.C., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J. & Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biological conservation*, *151*(1), 53-59.

Van der Sluijs, J.P., Amaral-Rogers, V., Belzunces, L.P., Van Lexmond, M.B., Bonmatin, J.M., Chagnon, M., Downs, C.A., Furlan, L., Gibbons, D.W., Giorio, C. & Girolami, V., (2015). Conclusions of the Worldwide Integrated Assessment on the risks of neonicotinoids and fipronil to biodiversity and ecosystem functioning.

Van Scoy, A. R., Yue, M., Deng, X., & Tjeerdema, R. S. (2013). Environmental fate and toxicology of methomyl. In *Reviews of environmental contamination and toxicology* (pp. 93-109). Springer, New York, NY.

van Swaay, C., Cuttelod, A., Collins, S., Maes, D., Munguira, M.L., Šašić, M., Settele, J., Verovnik, R., Verstrael, T., Warren, M. & Wiemers, M., (2010). European Red List of Butterfies Luxembourg: Publications Office of the European Union. *ASA du Lembronnet (63)-Projet de travaux dans l'Allier*.

Vanbergen, A. J., & Insect Pollinators Initiative. (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment*, *11*(5), 251-259.

Waddington, H., Snilstveit, B., Hombrados, J. G., Vojtkova, M., Anderson, J., & White, H. (2014). Farmer field schools for improving farming practices and farmer outcomes in low-and middle-income countries: a systematic review. *Campbell systematic reviews*, *10*(6).

WHO, (2003). Pesticide residue in food. In: International program on chemical safety Joint FAO/WHO meeting on pesticides results evaluations 2002, part 2 Toxicology.

Woodcock, B.A., Bullock, J.M., Shore, R.F., Heard, M.S., Pereira, M.G., Redhead, J., Ridding, L., Dean, H., Sleep, D., Henrys, P. & Peyton, J. (2017). Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science*, *356*(6345), 1393-1395.

Wratten, S. D., Gillespie, M., Decourtye, A., Mader, E., & Desneux, N. (2012). Pollinator habitat enhancement: benefits to other ecosystem services. *Agriculture, Ecosystems & Environment*, *159*, 112-122

Blank Page