Enhancing Knowledge Among Smallholders on Pollinators and Supporting Field Margins for Sustainable Food Security

Abstract

Agro-ecological intensification (AEI) harnesses natural processes, such as pollination, that support sustainable food production and can buffer against future risks. However, the transition from conventional agriculture, which relies on inputs that can damage natural ecosystems, to more sustainable food production, is knowledge-intensive. Here, we investigated knowledge gaps among smallholder farmers about pollinators and field margins in a bean agri-system in Tanzania. While 77% of farmers were familiar with and identified honeybees correctly prior to training, only 52% understood their role as a pollinator of crops. Furthermore, 80% and 98% of farmers were unaware of the significance of wild (solitary) bees or the importance of hoverflies as pollinators. A high level of synthetic agrochemical use was reported for the management of pests and weeds, particularly in the more agriculturally intensive production systems. However, an end-line survey conducted one year after training showed an increase in knowledge and the majority of farmers, 99%, 54% and 62% subsequently recognized honeybees, hoverflies and solitary bees respectively, by name. Furthermore, 95%, 69% and 60% of farmers understood the importance of honeybees, hoverflies and solitary bees respectively, as crop pollinators and natural enemies (for hoverflies). Similarly, a majority of farmers recognised the benefits of biopesticides as environmentally over synthetic pesticides as well as the value of field margins in supporting pollinators and other ecosystem services. We argue that, improving understanding among smallholder farmers of ecosystem services and their ecological requirements is both feasible and essential to achieving sustainable intensification in small holder farming systems.

Keywords: Crop production, Ecosystem services, Farming practices, Field margin plants, Pollination.

1.0 Introduction

Sustainable intensification depends on regulating ecosystem services such as pollination and is being increasingly adopted in smallholder farming (Pretty et al., 2018). Pollinators contribute to production in 75% of crops (Klein et al., 2007) but conventional technologies that rely on agrochemical inputs degrade ecosystem services, particularly pollination (Basu et al., 2016; Cusser et al., 2016; Potts et al., 2016) but also other ecosystem services and goods from non-crop land (Dale and Polasky, 2007; Krauss et al., 2011; Winqvist et al., 2012). Agro-ecological intensification (AEI) defines farming practices that harness these natural processes and can dramatically improve yields for smallholders (Garibaldi et al., 2016; Motzke et al., 2016; Sutter and Albrecht, 2016). Policy changes that augment pollination service are urgently required to maximize the yield potential of pollinator dependent crops (Dicks et al., 2016).

AEI is, however, knowledge-intensive, and adoption requires an understanding of the complexity of the underpinning principles. Non-crop agricultural landscapes provide refuge, nesting sites and forage for beneficial insects (Gillespie et al., 2016; Gurr et al., 2003; Landis et al., 2000; Nicholls and Altieri, 2013; Paredes et al., 2013; Sidhu and Joshi, 2016). The presence of suitable habitats around crop fields can support large communities of pollinators leading to increased interactions with nearby crops (Denisow and Wrzesień, 2015; Otieno et al., 2015, 2011), enhanced pollination services, and ultimately, higher yield (Dar et al., 2017; Garibaldi et al., 2013; Kevan, 1999; Kevan et al., 1990; Klein et al., 2007; Ricketts, 2004). Moreover, many beneficial insects build their nests and dwell on non-crop habitats adjacent to crops (Denys and Tscharntke, 2002; Klein, 2009; Marshall and Moonen, 2002). Therefore, effective management of field margins to maintaining non-crop vegetation is important in providing requirements for pollinators, but field margins also provide multiple ecosystem services, for example, in some AEI systems, *Desmodium* spp. have been reported to control parasitic striga weeds in a mixed cereal-cropping systems (Khan et al., 2011; Pickett et al., 2014; Tsanuo et al., 2003).

Knowledge of pollinators and their importance in crop production is important for smallholders to fully understand the relationship between pollinating insects and agricultural productivity and the conflicting impacts of conventional inputs such as pesticides and herbicides. However, evidence of farmer knowledge about pollinators is scarce, and in many regions this knowledge maybe limited (Tengö and Belfrage, 2004). For the successful transition to sustainable agriculture the integration of existing indigenous knowledge and scientific evidence is vital to raise farmers awareness and implement change (Woodley, 1991). For example, in some regions, local beliefs, local ecological knowledge and social protection techniques have been used to protect pollinators in horticultural landscapes (Tengö and Belfrage, 2004). Well informed farmers are better placed to transform unproductive farming systems to sustainable and productive ones (Marques et al., 2017) through the augmentation of ecosystem biodiversity (Cardinale et al., 2003). However, smallholder farmers may have limited knowledge about the importance of beneficial insects (Otieno et al., 2011). Instead, they may see insects in a broadly negative and collective way as crop pests or disease vectors (Marques et al., 2017; Smith et al., 2017). Knowledge enrichment will likely better equip farmers with an understanding of the economic importance of beneficial insects for crop yield, and thus lead to change in farmers' negative perceptions of insects, facilitating on-farm conservation.

Training of school-age youths by professionals about the identity and importance of common pollinators using school gardens, demonstration field plots, entomological specimens and audio-visual resources also can help to build students' knowledge for use in adulthood (Marques et al., 2017). But smallholder farmers may lack even fundamental knowledge to correctly distinguish between pests and beneficial insects and this must be understood before action to transition to AEI can be supported. The present study aimed to establish the level of knowledge about pollinators in bean farming systems in three elevation zones to determine the scope for adoption of AEI approaches that support pollination services in the light of recent evidence that pollination services can dramatically improve yield in smallholder farming systems (Garibaldi et al., 2016). Here we report the results of surveys pre- and post-training from three different elevation zones (low, mid and high) about the awareness and knowledge gaps among smallholder farmers in a Tanzanian agri-system of pollinators and their contribution in crop yields. Also, we discuss the potential importance of farm margin vegetation in sustaining pollinators as well as farming practices used in this region and present how knowledge through direct training can rapidly lead to change in farming behaviors towards AEI that can ultimately support pollinators and other ecosystem services.

2.0 Material and Methods

2.1 Ethic statement

At an early stage of this study, all farmers who were involved were fully informed about and agreed with the process, and willingly participated during interviews. All research ethics were observed and names of participants were anonymised when reporting their responses.

2.2 Study area

The study area was located in Moshi Rural District, Kilimanjaro in Tanzania (3.2468-3.3481° S, 37.5044-37.5411° E). All of our sites were selected along the slopes of Mt. Kilimanjaro and classified into three zones based on elevation gradient (Pabst et al., 2013; Soini, 2005). The zones were: low zone, Makuyuni (<1000 m a.s.l.), mid zone, Mieresini (1000-1499 m a.s.l.) and high zone, Mbahe (1500-1800 m a.s.l.). The main economic activity across the zones was arable farming, but most households also kept livestock, mainly cattle and goats, for milk and organic manure (Hemp, 2006a). The most common crops were maize (*Zea mays*) and common beans (*P. vulgaris*) although crops such as banana (*Musa* sp.), coffee (*Coffea arabica*), sunflower (*Helianthus annuus*), potato (*Solanum tuberosum*), sweetpotato (*Ipomoea batatas*) and a variety of vegetables (Hemp, 2006a; Schlesinger et al., 2015).

The low-elevation zone has two bean-cropping seasons; a rain fed season between March and May during long rains and an irrigation season between October and December during short rains (Mulangu and Kraybill, 2013). The area receives low annual rainfall compared with mid and high-elevation zones (Mulangu and Kraybill, 2013). The mid-elevation zone has the same cropping systems and seasons as the low zone and farmers in this belt grew mostly beans and maize (Schlesinger et al., 2015; Soini, 2005). Conversely, the high-elevation zone has one bean-cropping season between July and December and this is due to cold weather with prolonged wet period (Curry, 1939). Farmers in this area practiced more agro-forestry farming (Mmbaga et al., 2017) where banana, coffee and annual crops are intercropped with trees (Fernandes et al., 1985; Mulangu and Kraybill, 2013). Because climates and cropping systems varies with elevation gradient (Misana et al., 2012; Mulangu and Kraybill, 2013; Soini, 2005), insect diversity and composition at different times may differ with different experiences that could lead to different pre and post perceptions of the benefits of these insects. Also, farmers who rely on pollinator dependent crops may have pre existing perceptions about pollinators.

2.3 Survey designing and data collection

Prior to this study, research permits were granted by village government authority. The survey involved smallholder farmers growing a bean crop in the study area. Their names were obtained from the village offices located in each zone with the help of the local agricultural extension officer from each village. In each zone, 100 farmers who were willing to participate in this study were selected, with the principal criterion being that they grew beans. With their consent, farmers were interviewed face-to-face using a pre-tested structured questionnaire (See supplementary) in Swahili language (Tanzanian national language which all farmers spoke as either a first or second language with fluency). Later the interviewer visited farmers' bean field(s) to record and measure the size of the farm and status of the field margins. Information obtained from field observations were also included and discussed here. Data were collected during two household surveys, before (baseline) and after (end-line) training farmers. The baseline survey was conducted between March and April 2016 while the end-line survey was carried out in April 2018 using the same questionnaire to determine if farmers retained knowledge or changed farming practices after training.

The questionnaire was comprised of two main sections: demographic information and main questions of the study. The main questions were framed to explore farmers' knowledge of pollinators and their importance in crop production, value of field margin plants, field margins management and farming practices, and socio-economic importance of bean crop in improving livelihood of smallholder farmers.

To understand farmers' awareness of common pollinators before and after training, both printed coloured pictures (a high resolution photograph printed on to A4 paper) and a pinned specimen of each insect guild was shown to the respondent for identification during interview. Each respondent was asked to identify every insect by either using local or Swahili name and explain any importance to crop production they were aware of. Three pollinator specimens were collected from bean fields one week before interviews, using the following taxa of: honeybee (Hymenoptera: Apidae: *Apis mellifera*), hoverfly (Diptera: Syrphidae: *Eupeodes* sp.) and solitary bee (Hymenoptera: Megachilidae: *Megachile* sp.).

2.4 Training of Interviewers

A team of ten MSc. students from Nelson Mandela African Institution of Science and Technology (NM-AIST), Tanzania conducted the interviews with farmers in the study area. Prior to actual data collection, all interviewers were trained by researchers for two days at NM-AIST on ethics and data collection techniques so as to obtain quality data while maintaining a good relationship with the farmers' community. After training, the interviewers undertook two days pilot session in a nearby village in order to test questionnaires, familiarise with questions but also for researchers to evaluate the ability of each interviewer to do the work.

2.5 Training of smallholder farmers

To enhance farmers' knowledge we included a training component about pollinators and their importance in crop production, sustainable management of field margins and their value in supporting beneficial insects in bean agri-systems. To minimize the impacts to beneficial insects of current practices, we discussed alternative methods and practices to manage field margins as well as the use of non-synthetic pesticides, which are less harmful to beneficial insects and the surrounding environment. The training was done between March and April 2017; one year after baseline survey and it involved same farmers who were interviewed during our baseline survey. It was a participatory training and farmers were free to share their experience and opinions during indoor and field sessions. Printed coloured picture of insects, entomological box (with insect specimens) and beneficial field margin plants were among tools used during training. During training period, farmers showed interest and were keen to learn whatever was included in the training package to improve their crop production.

2.6 Botanical survey and sampling

We carried out a rapid vegetation survey to identify common flowering plants found along field margins of bean crop in three agri-system zones. The line transects of 50m were established in 6 bean farms (two farms in each zone). At each 10m measure of transect, two quadrats ($1m^2$ by size) were established before and after a 10m mark to assess the plant community in field margins. Plant species were identified on site and vouchers of unknown plant species were collected in duplicate and sent to National Herbarium of Tanzania, Arusha and Royal Botanic Garden, Kew, for identification.

2.7 Data entry and Statistical analysis

Farmers responses, measured in percentages of farmers falling into different groups of categorical answers, were analysed using R statistical software (R Core Team, 2017). To test significant differences between farmers' responses in three zones, we performed a Kruskal-Wallis rank sum test (H) (Sheskin, 2011) because the distributional condition for ANOVA was not met.

3.0 Results

3.1 Farm size, Gender and Age of respondents

Of the 300 respondents in this study 61% (182) were female and 39% (118) male. Higher number of female respondents is agreeing with previous studies that more women grow beans compared with men (Broughton et al., 2003). No differences in knowledge between male and female respondents were recorded with respect to the identification of the three pollinators; honeybee ($H = 2.2546$, $df = 1$, $p = 0.1332$), hoverfly ($H = 0.0004$), $df = 1$, $= 0.9837$), solitary bee ($H = 0.3467$, $df = 1$, $p = 0.556$). Similarly, we found no significant difference of knowledge between male and female respondents regarding the importance of pollinators in crop production: honeybee ($H = 1.9633$, $df = 1$, $p = 0.1612$), hoverfly ($H = 0.2960$, $df = 1$, $p = 0.5864$), solitary bee ($H = 0.0455$, $df = 1$, $p = 0.831$). We also found that the age of farmers engaged in bean cropping was evenly distributed and the knowledge of pollinators between farmers did not vary significantly by age; honeybee ($H = 55.145$, $df = 54$, $p = 0.4311$), hoverfly ($H = 43.427$, $df = 54$, $p = 0.8478$), solitary bee ($H = 68.767$, $df = 54$, $p = 0.08508$). Likewise, there was no significant difference of knowledge by age between farmers in three zones of the importance of pollinators in crop production; honeybee ($H = 50.75$, $df = 54$, $p = 0.6005$), hoverfly ($H = 38.912$, $df = 54$, $p = 0.9393$), solitary bee ($H = 17.594$, $df = 54$, $p = 1$). Most farmers in the mid and high zones (64% and 69% respectively) worked in farms of not more than 0.20 hectares whereas for farmers in the low altitude only 38% had farms of this size. The average farm size across all zones was 0.27 hectares.

3.2 Farmers' knowledge of common pollinators before and after training

Information on farmers' knowledge of pollinators was obtained by asking respondents to identify each insect by either using a local or Swahili name. Overall 77% of farmers identified the honeybee correctly while 5% identified it incorrectly and 18% said they did not recognise the insect at all. Only 5% of farmers were able to correctly identify hoverflies, with 15% identifying it incorrectly and 80% did not recognise the insect. No farmers who identified the solitary bee correctly by any local or Swahili name with 98% not knowing the insect at all and 2% identifying it incorrectly. Generally, there was little variation in knowledge among farmers at different altitudes although significantly more farmers in mid zone (84%) recognised the honeybee compared with those in low (66%) and high (79%) zones ($H = 10.074$, $df = 2$, $p = 0.0065$). We also found no significant difference in knowledge of hoverflies ($H = 2.5695$, $df = 2$, $p = 0.2767$) and solitary bees ($H = 5.5397$, $df = 2$, $p = 0.0627$) between farmers at different altitudes.

One year after training, awareness of honeybees among smallholder farmers increased by 34%, 14% and 20% in low, mid and high zones respectively. Only 1% of farmers in the high zone identified the insect incorrectly and 2% of farmers in the mid zone were not aware of this insect. The results showed a significant increase in knowledge retention among farmers of hoverflies by 25%, 49% and 73% in low, mid and high zones respectively, compared with pre-training results. We found only 39%, 22% and 24% of farmers who identified the insect incorrectly while a small group of farmers failed to do so (Table. 1). There was a significant increase of knowledge of solitary bees where more farmers in the low zone (73%) were able to identify a solitary bee by name compared with 59% in the mid and 55% in high zone. Even after training, we still recorded 16%, 32% and 30% of farmers in low, mid and high zones who identified solitary bee incorrectly while a significant low number of farmers said they were unaware of the insect (Table 1).

3.3 Farmers' knowledge of the importance of pollinators in crop production before and after training

Surprisingly only 53%, 56% and 45%, of farmers in the low, mid and high zones respectively, expressed awareness of the importance of honeybees as a crop pollinator. However, more alarmingly a significant minority of farmers identified honeybees as a pest and some did not know the potential importance of this insect in crop production reflecting the perception that many farmers see all insects as problematic rather than beneficial. There was no significant difference in knowledge among farmers across three zones on the importance of honeybee in crop production ($H = 0.91476$, $df = 2$, $p = 0.6329$). Knowledge among farmers in the three zones regarding the role of hoverflies in pollination differed significantly ($H = 8.1048$, $df = 2$, $p = 0.0174$) with majority of farmers being unaware. Only 14%, 7% and 1% of farmers in the low, mid and high zones respectively, recognised the insect as pollinators. No farmers responded to indicate any prior knowledge regarding the role of wild solitary bee species as crop pollinators while a minority identified solitary bees as crop pest (Table 2). There was no significant difference in knowledge between farmers in three zones regarding the importance of solitary bees as pollinators of crops ($H = 0$, $df = 2$, $p = 1$).

One year after training, we recorded a significant increase in knowledge between farmers ($H = 27.675$, $df = 1$, $p < 0.001$) where the majority, 95%, 92% and 98% of them in the low, mid and high zones reported understanding the importance of honeybees as crop pollinators. We recorded variable knowledge between farmers regarding the importance of hoverflies in crop production and the majority of farmers recognised this insect as a pollinator (24% low, 18% mid and 33% high), natural enemy of pests (18% low, 12% mid and 20% high) and others recognised it as both pollinator and natural enemy (22% low, 33% mid and 27% high). Knowledge about solitary bees was also enhanced and retained post-training with the majority of farmers, 52%, 65% and 63% in the low, mid and high zones respectively, recognizing and reporting solitary bees as pollinators with only a minority of farmers still considered the insect a pest or were not aware of the insect at all (Table 2).

3.4 Management of field margins in bean agri-systems

In the baseline survey, farmers reported that they frequently cleared their field margins and the most common methods were cutting and burning (Fig. 1). We found a significant variation in frequency with which low zone farmers clear their field margins more frequently compared with those in the mid and high zones ($H = 17.598$, $df = 2$, $p < 0.001$). However, one year after training, we recorded fewer farmers, 55% and 32% in the low and high zones respectively, who cut their field margins while in the mid zone we recorded a slight increase although this was in concert with a significant reduction in the farmers burning field margins (Fig. 1). At the baseline, 8%, 33%, 5% of farmers in the low, mid and high zone respectively, reported burning their field margins, the number decreased to 4%, 9%, 3% after training. No farmers applied herbicides to manage weeds in the field margins compared with pre- training where 1% and 3% of farmers in the low and mid zones respectively, did so.

3.5 Farmers' knowledge of the role of field margin plants in bean agri-systems

We found 27%, 56% and 55% of farmers in the low, mid and high zones respectively, who did not mention beneficial plants as a feature of their bean cropping systems. Although we observed various flowering plants species such as *Tithonia diversifolia*, *Ageratum conyzoides*, *Commelina foliacea*, *Neonotonia wightii*, *Bidens pilosa* and *Desmodium uncinatum* along margins of bean fields which were frequently visited by insects (Supplementary Table 1), 64%, 35% and 31% of farmers in the low, mid and high zones respectively, declared that their bean field margins do not include beneficial plants. However, a minority of farmers (3%) in the low zone cited flowering plants as important while 9% in the mid zone reported the presence of beneficial plants but they were not able to describe them specifically, even using local names. A small group of farmers mentioned *Thevetia peruviana*, *Acacia tortilis*, *Persa americana*, *Azadirachta indica* and *Prunus* spp. as beneficial plants found within and along their bean fields. Coffee (*Coffea arabica*), cassava (*Manihot esclulenta*), collard greens (*Brassica* spp.) and sunflowers (*Helianthus annuus*) were also listed as beneficial plants when intercropped with beans since they increased the number of honeybees in bean field. There was a statistically significant difference between the three zones in farmers' knowledge of beneficial plants ($H = 30.056$, $df = 2$, $p < 0.001$), with the majority of farmers in the low zone not mentioning beneficial plants in their field margins. Across elevation zones, farmers listed various benefits of field margin plants where more farmers in the high zone reported fodder and erosion control as major benefits from margin plants compared with low and mid zone farmers ($H = 27.753$, $df = 2$, $p < 0.001$). In the baseline survey, no farmers reported the importance of marginal plants in attracting pollinators. However, one year after training, we recorded between 7 and 11% of farmers who recognised the importance of these plants in promoting pollinators (Fig. 2).

3.6 Farming practices by smallholder farmers in bean agri-system

In the baseline survey, approximately 75% and 87% of farmers in low and mid zones respectively, reported application of synthetic pesticides, whereas in the high zone where few did so (Fig. 3). The most common pesticide products were Selecron 720EC (Profenofos), Karate 5EC (Lambda-cyhalothrin-Pyrethroids) and Dursban 24ULV (Chlorpyrifos). The key advantages reported by farmers for using synthetic pesticides were not surprisingly their apparent efficacy at controlling pests but also their ease of use, while the disadvantages reported included toxicity and cost indicating that farmers were aware of the dangers of using synthetic products. A minority of farmers didn't report any drawbacks.

Although the same farmers who were interviewed during the baseline survey were trained about the effects of synthetic pesticides application to beneficial insects, the results from end-line survey (one year later) indicate many farmers still applied these chemicals to control pests. However, we recorded a change in rates of application; the number of farmers who did not apply these products increased to 41% and 52% in the low and mid zones respectively, from 25% and 13% at baseline, while we recorded less change in the high zone where little pesticide was used at the outset (Fig. 3).

On the other hand, we found only a small numbers of farmers using organic and/or botanical pesticides (Fig. 4). The farmers who did use these reported that their being less toxic and affordable as major reasons for adopting them. Organic pesticides reported included ash, cattle urine and dung and botanicals made from a part of or the whole plant that has insecticidal and/or repellent properties. Farmers mentioned plants such as *Tithonia diversifolia*, *Azadirachta indica*, *Tephrosia vogelii*, *Tagetes minuta* and *Aloe vera* as common botanical pesticides in the area. One year after training, we recorded a significant increase in number of farmers who either applied botanicals, organic pesticides or a mixture of botanicals and organic pesticides to control pests (Fig. 4).

3.7 Socio-economic importance of bean crop to smallholder farmers

We found beans were equally popular across the zones ($H = 2.5383$, $df = 2$, $p = 0.2811$) and were important for food security as well as income. Our results showed that 51%, 60% and 21% of farmers in low, mid and high zones respectively, earned an income up to 100 USD after selling beans in the local markets during first season of 2016. Although we found some farmers earning up to 400 USD per cropping harvest, 36% of farmers in the low, 29% in the mid and 80% in high zones did not earn any income in that particular season. Consequently, only 1% and 2% of farmers in the low and mid zones respectively, earned more than 300 USD during the season. There was significant variation in income earned by farmers across three zones after selling beans during this season ($H = 49.564$, $df = 2$, $p < 0.001$). The majority of farmers in high zone did not have enough beans to sell in the market after taking what they needed from their harvest. For those who sold beans their income was mainly spent on clothes, food, household supplies, paying school fees for their children, building or renovating their houses and medical services.

4.0 Discussion

4.1 Farmers' knowledge of common pollinators before and after training

The majority of farmers in this region lack knowledge about pollinators and their importance in improving crop yield, but it is not linked to age or gender. Most farmers were unable to identify hoverflies and solitary bees and surprisingly few identified honeybees. Smith et al. (2017) also reported that farmers who grow a variety of pollinator dependent and non-dependent crops in India were not able to recognise solitary bees and this may highlight an important knowledge gap since wild pollinators invariably contribute to yield benefits in most pollinator dependent crops whereas honeybees do not always do so (Garibaldi et al., 2013). Similarly, Kasina et al. (2009) reported farmers being aware of honeybees but less so for other pollinators. It may be that honey bee keeping is widely practised around farmlands in the surveyed areas primarily for their honey and wax and associated income, with their importance to crop yield being less well understood. Alternatively, farmers in our study may have obtained the knowledge from previous agricultural extension work around beekeeping programs (Lyver et al., 2015; Soini, 2005). Although we still recorded some famers who were unable to identify honey bees, hoverflies and solitary bees correctly one year after training, the awareness significantly increased compared to pre-testing results (Table 1) indicating that knowledge gaps can be closed through education.

4.2 Farmers' knowledge of the importance of pollinators in crop production before and after training

While some farmers were able to recognise these insects, particularly honeybees, most of them categorised the insects as pests and some did not recognise the insects at all, let alone their potential role in crop production. This has been a well-recognised challenge in Africa due to the unfavourable perceptions that farmers have of insects as a result of little knowledge of their economic importance (Frimpong-Anin et al., 2013; Munyuli, 2011; Otieno et al., 2011). Our study observed that honeybees were recognised by most farmers in the surveyed area while lacking information on hoverflies and solitary bees. Since we have observed some differences in the knowledge about pollinators among farmers in three zones, further investigation was needed to determine how farmers access agricultural information and identify the best approaches for wider scale knowledge transfer about pollinators' to farmers and how training can support this.

The responses of farmers surveyed one year after training changed significantly indicating that farmers acquired and retained knowledge and even change perceptions about landscape and land management practice. For example, significantly more farmers reported being aware of the importance of honeybees, hoverflies and solitary bees as pollinators of crops compared with the responses recorded during the pre-training survey (Table. 2). Although in the baseline the majority of farmers had little knowledge of pollinators and their importance, training strengthened their knowledge and even after one year post training, many were still able to recognize the insects and their function. The overall results suggest that training is an essential and effective tool to change farmers' knowledge and perceptions and to change their agricultural practices since. Increased understanding about pollinators and their importance in crop pollination is necessary for smallholder farmers to recognise the connection between these insects and agricultural productivity, therefore, such events should be encouraged. The knowledge changes reported here suggest that smallholder farmers in this area would have continued to hold the same negative view they had before hand if they had not received training. More studies should also focus on barriers and constraints faced by farmers when they need to access agricultural information that would help to improve production.

4.3 Management of field margins in bean agri-systems

Field margin management is an important consideration in agro-ecological intensification (AEI) since it can affect the pollinator populations in cropping landscapes while their diversity and abundance is influenced by the availability of specific floral forage resources and nesting sites in non-crop habitats when the crop is not in flower (Blaauw and Isaacs, 2014; Morandin and Kremen, 2013; Nicholls and Altieri, 2013). In our baseline survey, some farmers reported that they cleared their field margins more often and the most common methods were cutting and burning which can simultaneously decimate above-ground nesting species (Brown et al., 2017; Ne'eman et al., 2000). This practice may negatively affect pollinator populations with consequences for crop yields since frequent mowing of vegetation is known to reduce habitat and food resources (Buri et al., 2014; Halbritter et al., 2015; Kennedy et al., 2013; Potts et al., 2003). On the other hand, timely and planned burning can boost some pollinating guilds in forestlands but due to its complexity, adopting this in bean farming would need to be implemented with much more consideration to avoid the negative impacts (Campbell et al., 2007; Potts et al., 2005).

One year after training, fewer farmers cut or burnt their field margins and no farmers applied herbicides to manage weeds in the field margins compared with pre- training results (Fig. 1).

The results suggest that changing farm management among farmers through knowledge enhancement may help to conserve beneficial plants in bean agri-systems and support agroecological intensification.

4.4 Farmers' knowledge of the role of field margin plants in bean agri-systems

The majority of farmers did not recognise the importance of field margin plants in supporting beneficial insects in bean agri-systems, and some declared that their bean field margins do not include beneficial plants. This suggests that most farmers may lack knowledge about farming practices that enhance pollinators, and where they do identify potentially beneficial plant species they fail to link agricultural practices, pollination services and crop production. Our study found differences in knowledge of beneficial plants among farmers by zones, and this may be due to differences in vegetation composition including species diversity in field margins that varies by altitude (Hemp, 2006b), which may also affect farmers' knowledge. Where margin plants were reported to offer benefits to smallholder farmers, the most common benefits reported were livestock fodder and erosion control but varied with zones (Fig. 2). More farmers in the high zone reported fodder and erosion control as major benefits from margin plants compared with low and mid zone farmers. This zonal variation may be explained because most farmers in this agri-system keep livestock in stalls so require fodder daily for them (Hemp, 2006a). These farmers may also benefit more from the value of non-crop vegetation to control soil erosion since their farms are located in high altitudes (above 1500 m a.s.l.) where rain can wash away soil. The use of plants to mitigate against soil erosion is a common practice in many highland areas (Angima et al., 2000; Zuazo and Pleguezuelo, 2008). Although non-crop vegetation nearby crop fields has been reported to support pollinators and other beneficial insects (Kennedy et al., 2013; Öckinger and Smith, 2007; Otieno et al., 2015; Paredes et al., 2013), farmers did not mention this benefit at the start of this study, suggesting that they lack knowledge. However, one year after training, we recorded a small group of farmers who recognised the importance of these plants in supporting pollinators (Fig. 2).

During the botanical survey, we found some fields with wide and richer margins while some had narrow margins with fewer plants species which may determine insect diversity and local abundance (Kohler et al., 2008; Rundlöf et al., 2018). This study argues that farmers' fields with lower flower richness could opt to enrich their field margins by sowing native flowering plants to promote pollination services (Feltham et al., 2015; Korpela et al., 2013; Sidhu and Joshi, 2016). However, the context and options available to smallholders must be established to understand the scope to support them to move towards pollinator conservation. Although it may take time to maximize pollination services, farmers are likely to change their farming practices if they are assured through demonstration that higher diversity and richness of pollinators enhances crop yields. Along with supporting pollinators, added benefits of field margin vegetation if implemented more widely include carbon sequestration; nourishment (food products), firewood and fibers; air quality and climate regulation; soil quality improvement; weed, pest and disease control; water purification; and cultural services (Moonen and Bàrberi, 2008; Mudavanhu et al., 2017; Richardson, 2010; Swift et al., 2004).

4.5 Farming practices by smallholder farmers in bean agri-system

Most farmers, particularly in the high zone, practiced mixed cropping, a typical system practiced by Chagga tribes people, the dominant ethnic group in the study area (Hemp, 2006a; O'kting'ati et al., 1984; Soini, 2005). Although farmers use synthetic pesticides to control insect pests, they are broad spectrum and so can have deleterious impacts on pollinators (Brittain et al., 2010; Henry et al., 2012; James and Xu, 2012; Melisie and Damte, 2017). They reduce pollinator species abundance and diversity by killing them directly or affecting their foraging behaviour and physiological activities (Brandt et al., 2016; Fischer et al., 2014; Gill et al., 2012; Gill and Raine, 2014). Although the same farmers who were interviewed during the baseline survey were trained about the effects of synthetic pesticides application to beneficial insects, the results from the end-line survey indicate many farmers still applied these chemicals to control pests. This study argues that continuous training about the effect of these chemicals to the environment, and intensive demonstration on the use of less-harmful bio pesticides may help to reduce the number of farmers who uses synthetic pesticides in this region.

Although organic and botanical pesticides can be effective at controlling pests and cause less harm to beneficial insects, human health and the surrounding environment (Amoabeng et al., 2013; Campos et al., 2016; Mkenda et al., 2015; Stevenson et al., 2017), we found only a small numbers of farmers using these pest management options (Fig. 4). Although some farmers mentioned a few plant species used as botanical pesticides in the area, none were aware of the potential of field margin species such as *A. conyzoides* as a botanical insecticide (Amoabeng et al., 2014; Rioba and Stevenson, 2017). Recent studies conducted in the same agricultural landscape, also reported high performance of *T. diversifolia* and *T. vogelii* extracts in controlling pests of *P. vulgaris* with lower negative impacts on beneficial arthropods (Mkindi et al., 2017; Tembo et al., 2018).

Since we found a small group of farmers using non-synthetic pesticides, the training also aimed at building farmers' capacity on various non-synthetic pesticides, which may be used as alternatives to synthetic pesticides to avoid deleterious effects to beneficial insects. The significant changes recorded one year after training suggest that farmers were willing to reduce the use of synthetic pesticides if they were assured through demonstration of the effectiveness of alternatives. The experience shows that farmers rely on synthetic pesticides in the absence of knowledge and guidance on alternative methods to control pests (Williamson et al., 2008).

4.6 Socio-economic importance of bean crop to smallholder farmers

Beans were reported to be an important dietary component, consumed around three times a week for the majority of farmers and daily for a minority which corroborates previous reports of its importance in most areas of Tanzania (Hillocks et al., 2006). They were important for food security as well as income, often replacing coffee (Maghimbi, 2007). Since we have observed the economic importance of beans in improving the livelihood of people in this region, intervention to increase its production is justified. Living standards and food security is likely to be improved among poor households in this region if bean production increases.

5.0 Conclusion

This study recorded significant knowledge and behavior changes among farmers one year after undergoing training. We therefore conclude that training can help to bridge knowledge gaps among farmers and improve understanding of the relationship between management activities and agro-biodiversity in crop production. However, there is a need for farmers to be equipped with knowledge and tools to enable them to make informed decisions about their farm management practices and be empowered with information about better alternatives for food production that they can adopt. Both farmers and beekeepers need to understand the major role of bees in crop production rather than focusing only on honey production and related hive products. Meanwhile, their role as pollinators in improving crop production is largely neglected at a policy level. This is unfortunate, as studies from other countries indicate that the value of bees as pollinators for the production of numerous fruits, vegetables and nuts far outweighs the value of honey production and beekeepers may be well paid for their bees to provide pollination services for higher-value crops (Hoover and Ovinge, 2018; Rucker et al., 2012) and if the beekeepers are themselves farmers, they will benefit directly from improved yield. Formulation of participatory policy (Maderson and Wynne-Jones, 2016) would encourage conservation of pollinators at national level since it will enable circulation of information among communities of farmers and beekeepers. This study has highlighted the need for agro-ecological programs, workshops, seminars and training events to increase smallholders' knowledge of beneficial invertebrates and the value of field margin plants in supporting agricultural biodiversity.

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Fig. 1. Farmers' responses about their preferred methods used to manage field margins in bean agri-systems. NC=No Clearing of field margin, NFM=No Field Margin.

Fig. 2. Farmers' responses about the roles of field margin plants in bean agri-systems, presented before and after training activities had taken place, and disaggregated by elevation zone.

Fig. 3. Farmers' responses regarding application of synthetic pesticides in bean agri-systems before and after training activities had taken place, and disaggregated by elevation zone.

Fig. 4. Farmers' responses regarding application of non-synthetic pesticides in bean agri-systems before and after training activities had taken place, and disaggregated by elevation zone.

Fig 1.

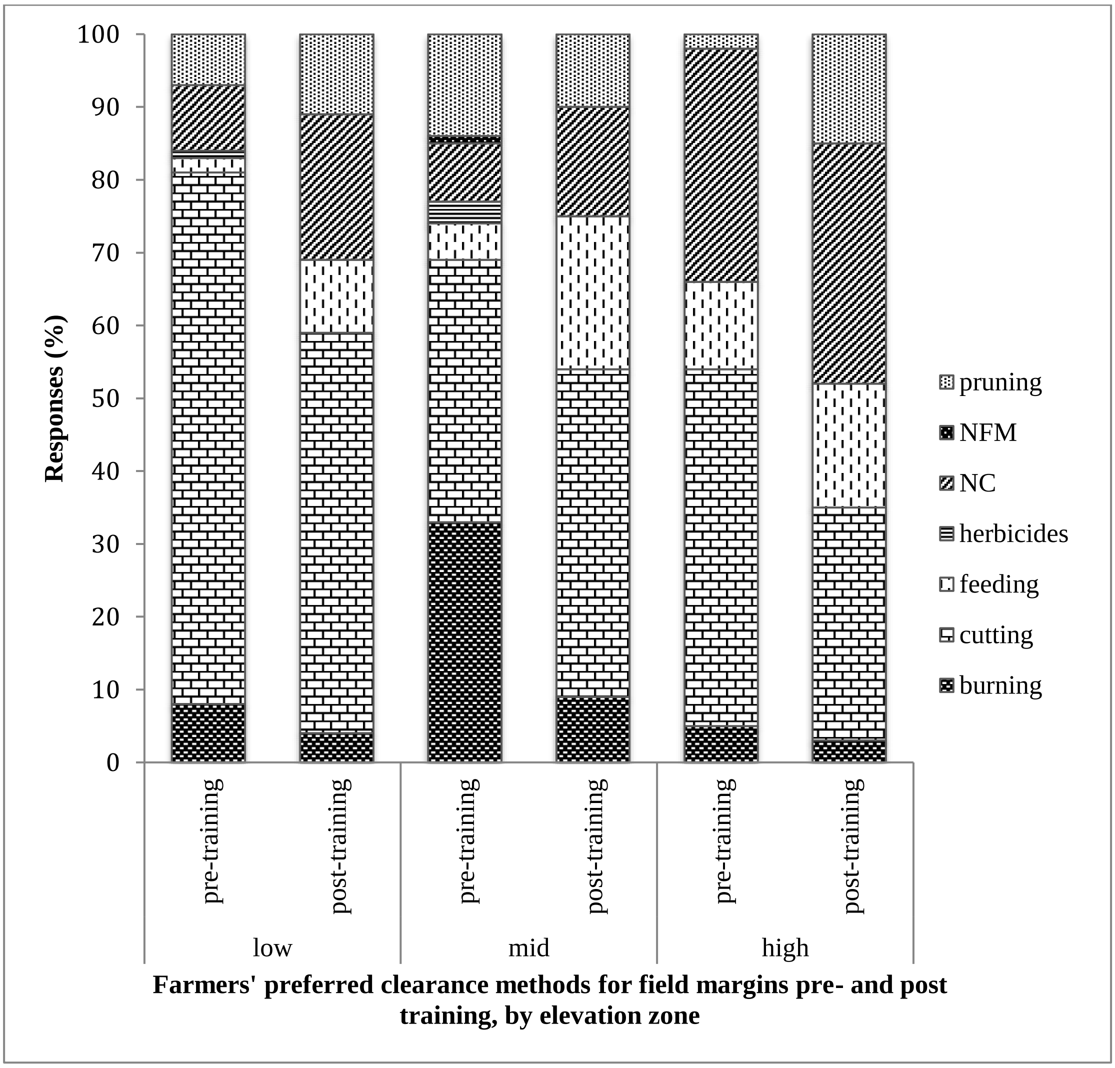


Fig 1. Revised

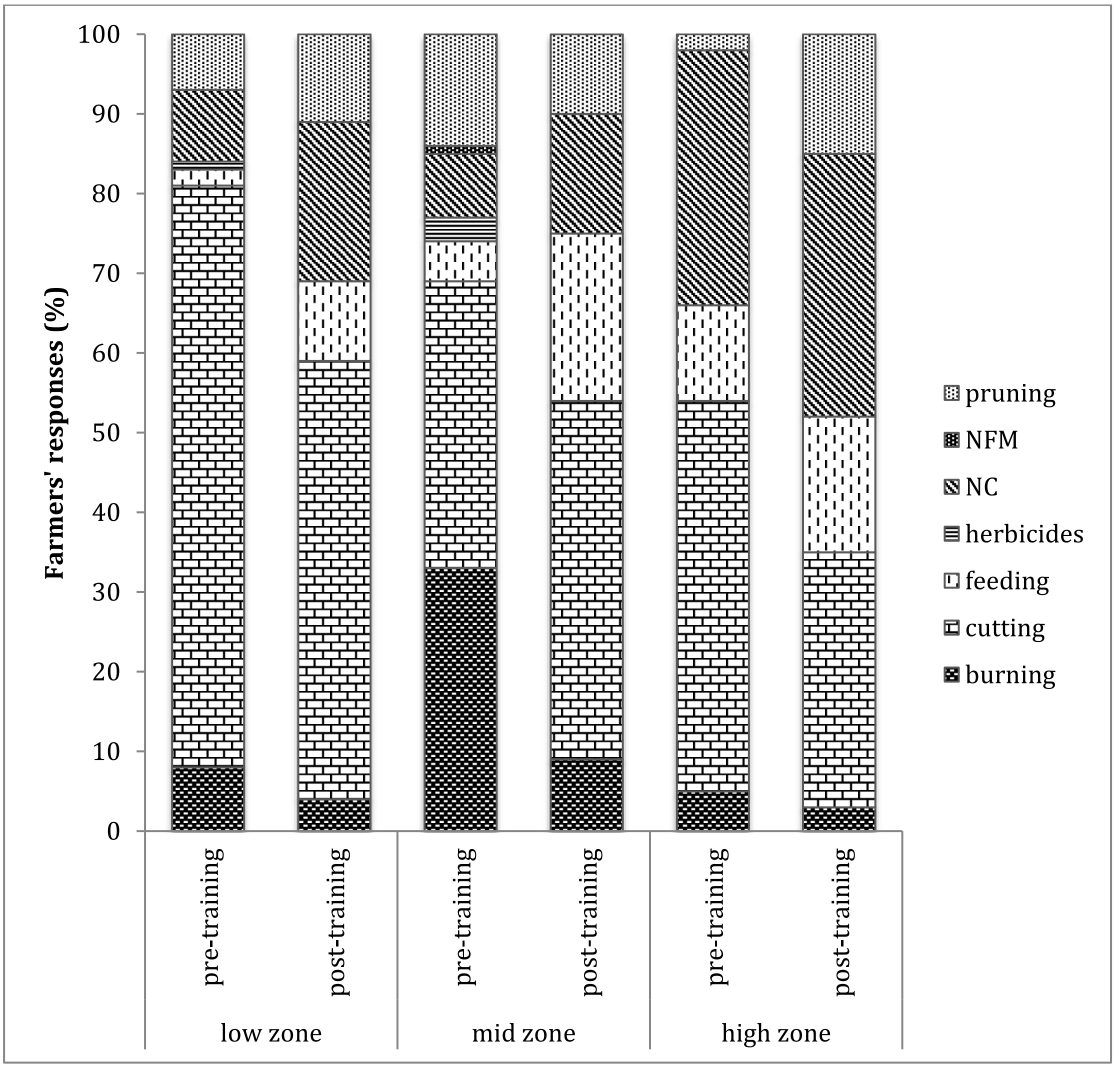
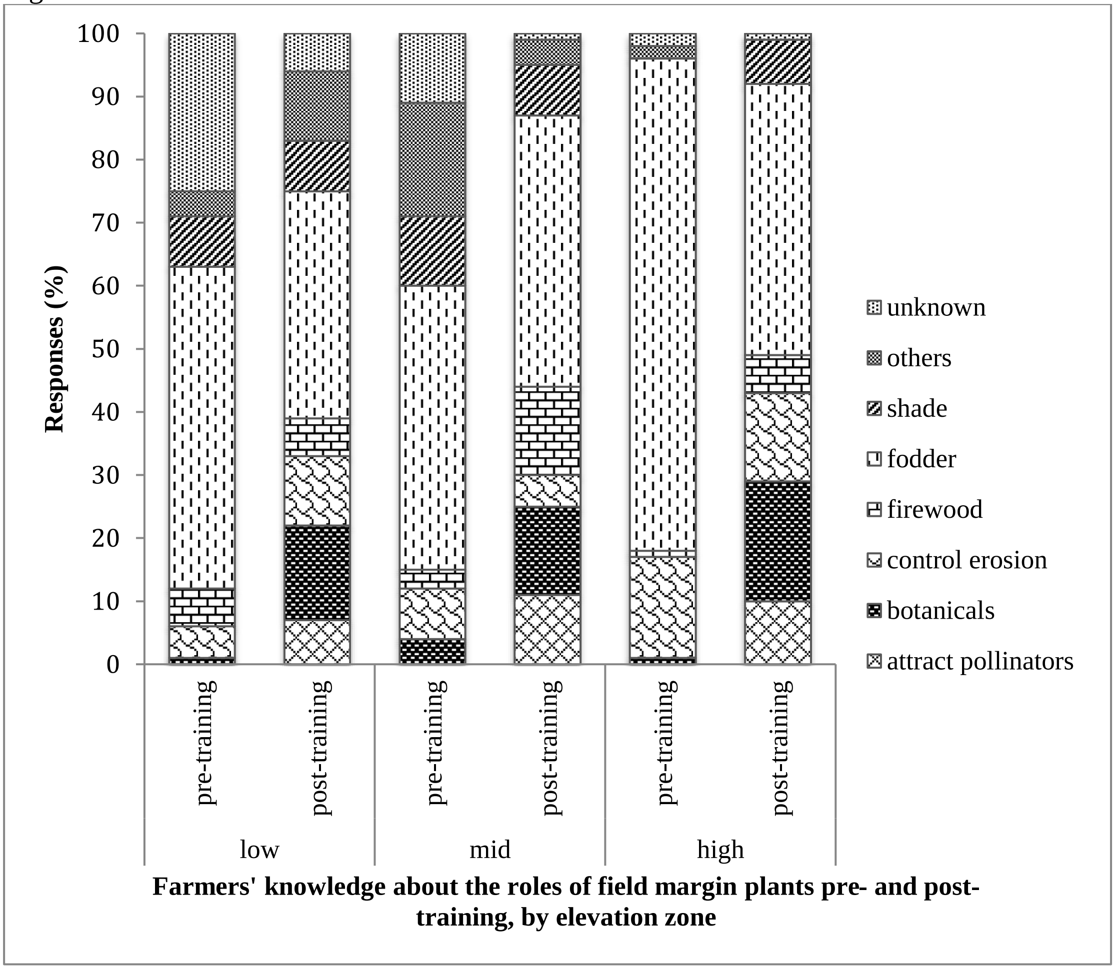

Farmers' responses (%)
100
90
80
70
60
50
40
30
20
10
0
pre-training
post-training
pre-training
post-training
pre-training
post-training
low zone
mid zone
high zone
pruning
NFM
NC
herbicides
feeding
cutting
burning

Fig 2.



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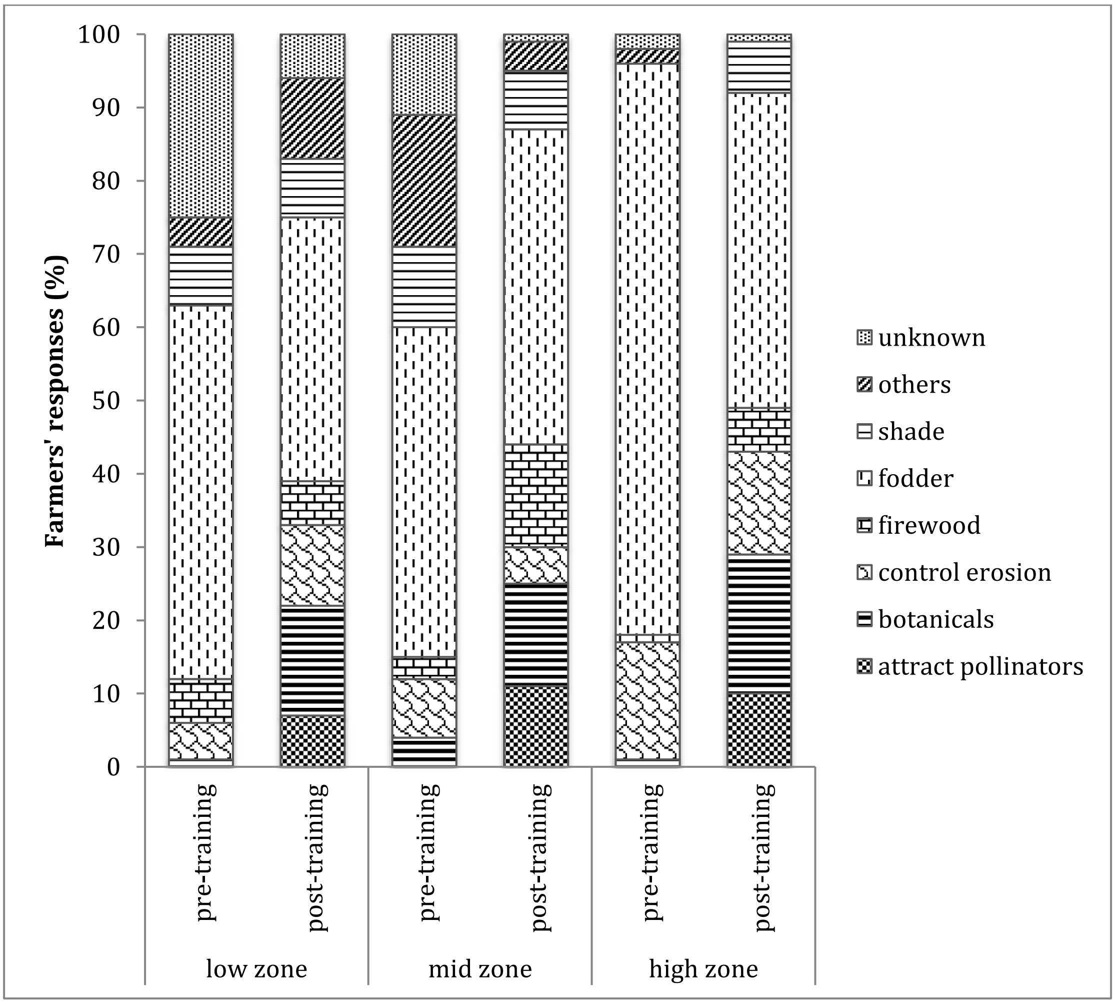

100
90
80
70
60
50
40
30
20
10
0
Farmers' responses (%)
pre-training
post-training
pre-training
post-training
pre-training
post-training
low zone
mid zone
high zone
unknown
others
shade
fodder
firewood
control erosion
botanicals
attract pollinators

Fig. 3.

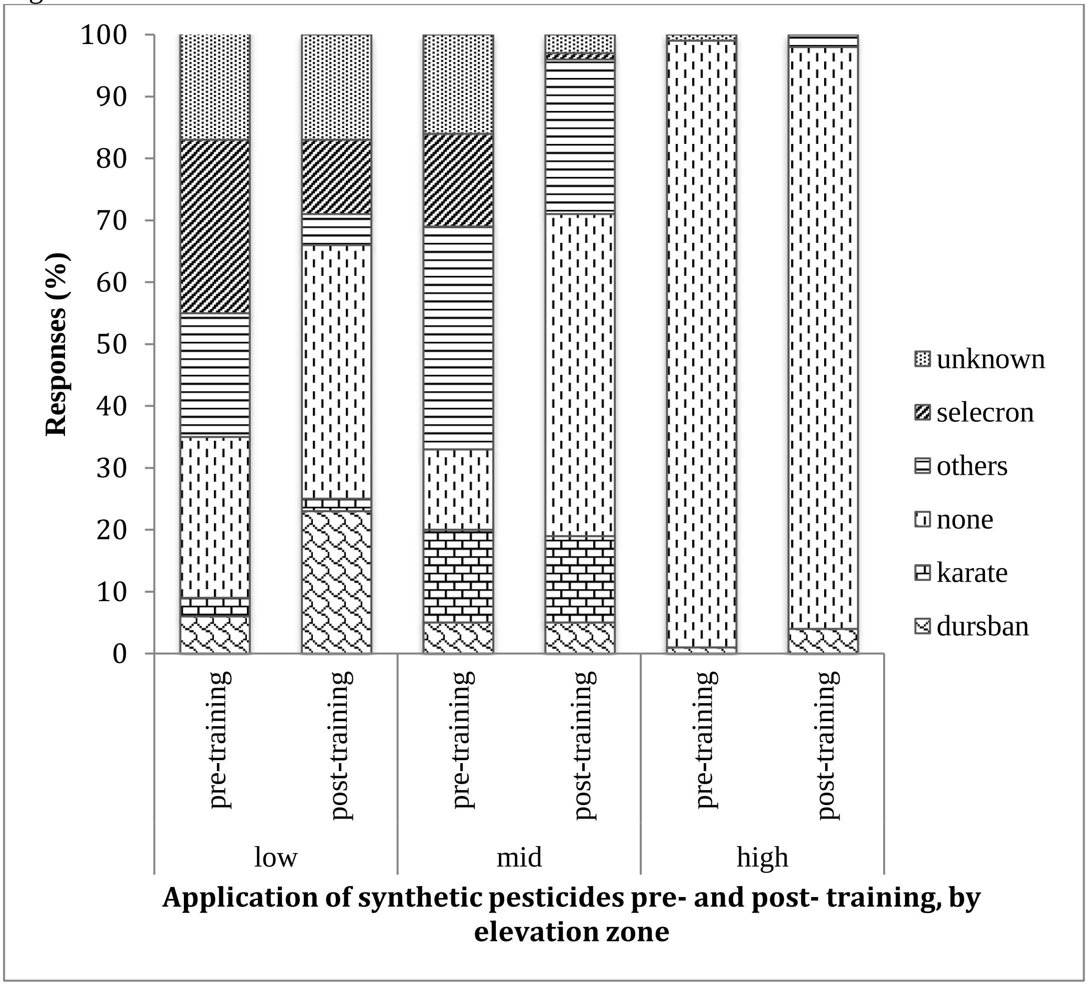


Fig 3. Revised

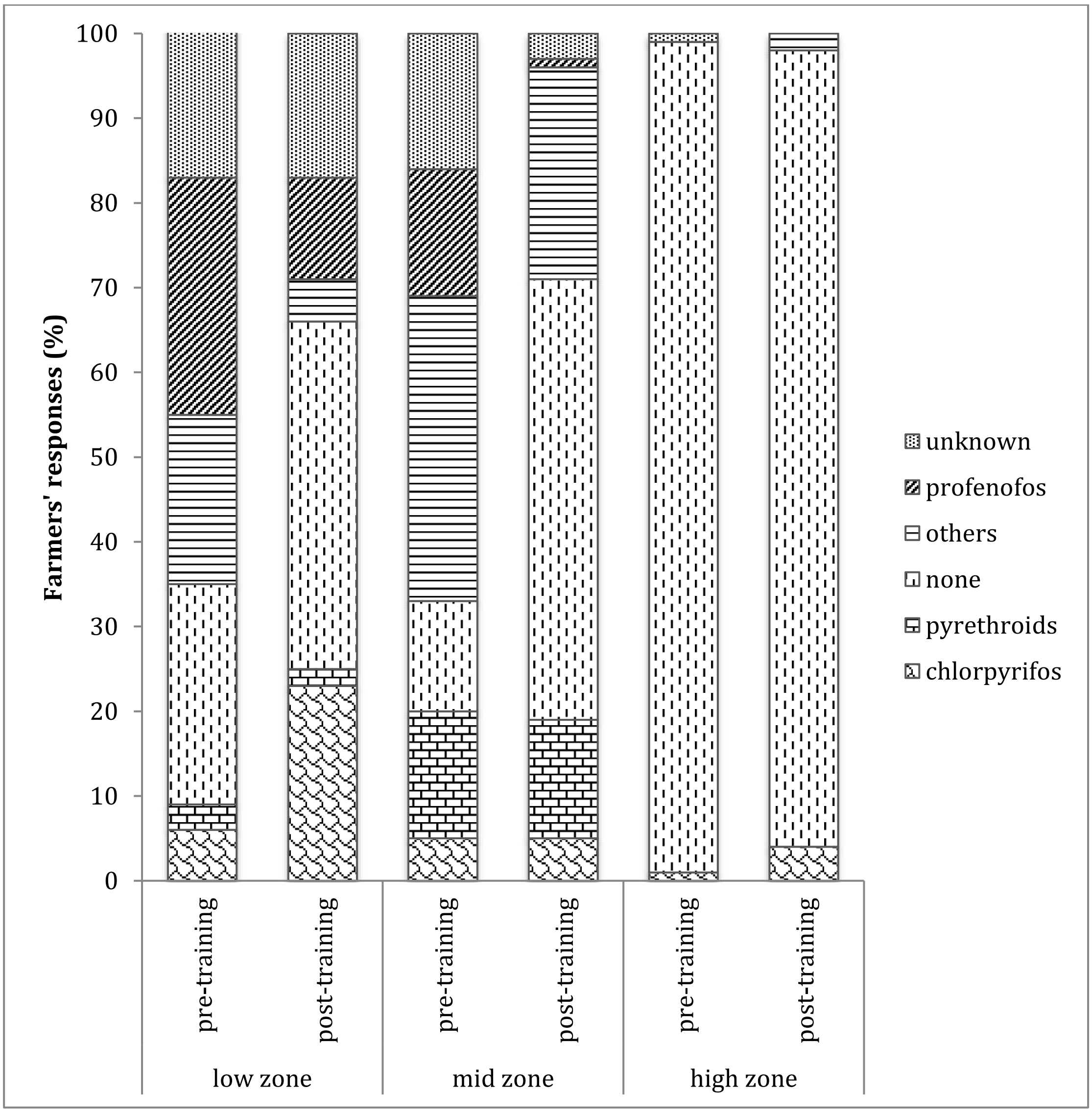

Farmers' responses (%)
100
90
80
70
60
50
40
30
20
10
0
unknown
profenofos
others
none
pyrethroids
chlorpyrifos
pre-training
post-training
pre-training
post-training
pre-training
post-training
low zone
mid zone
high zone

Fig. 4

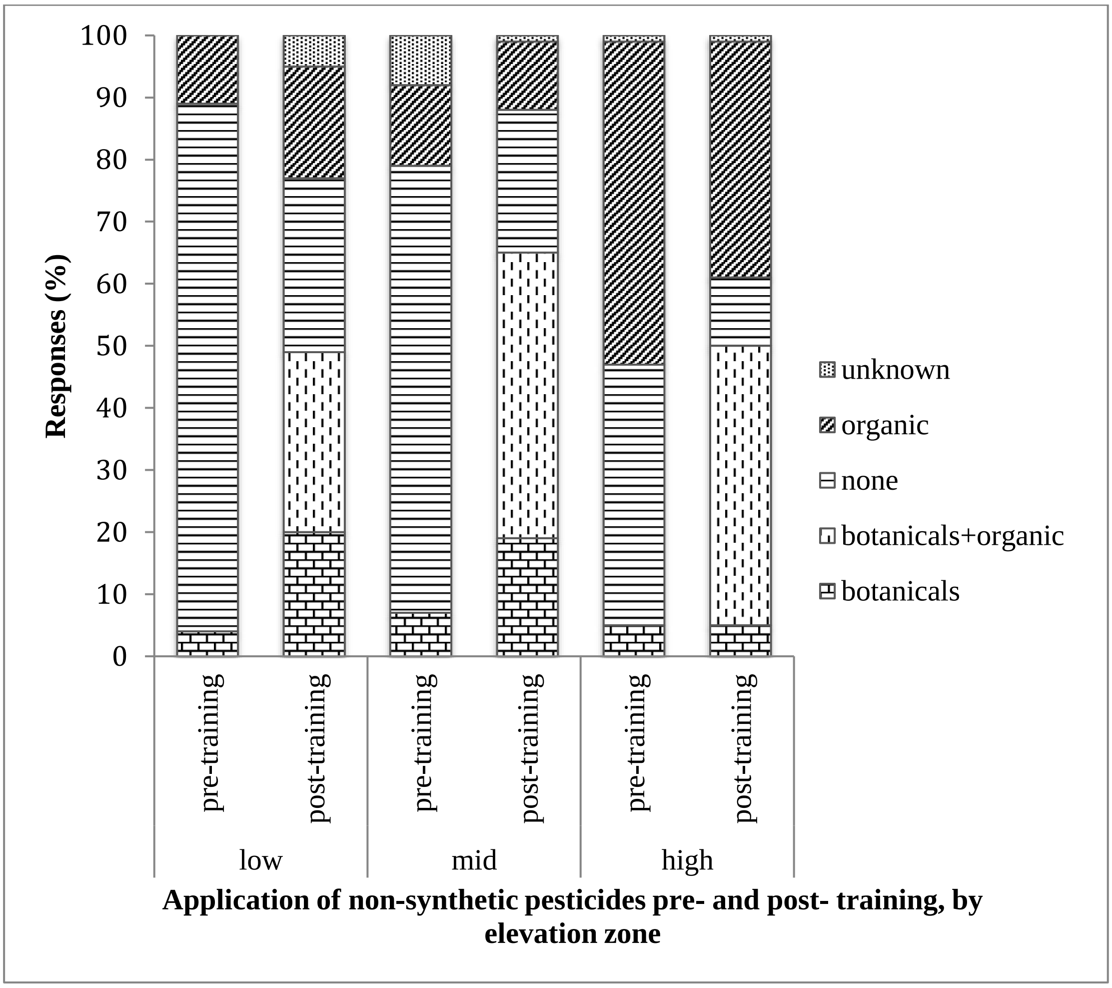
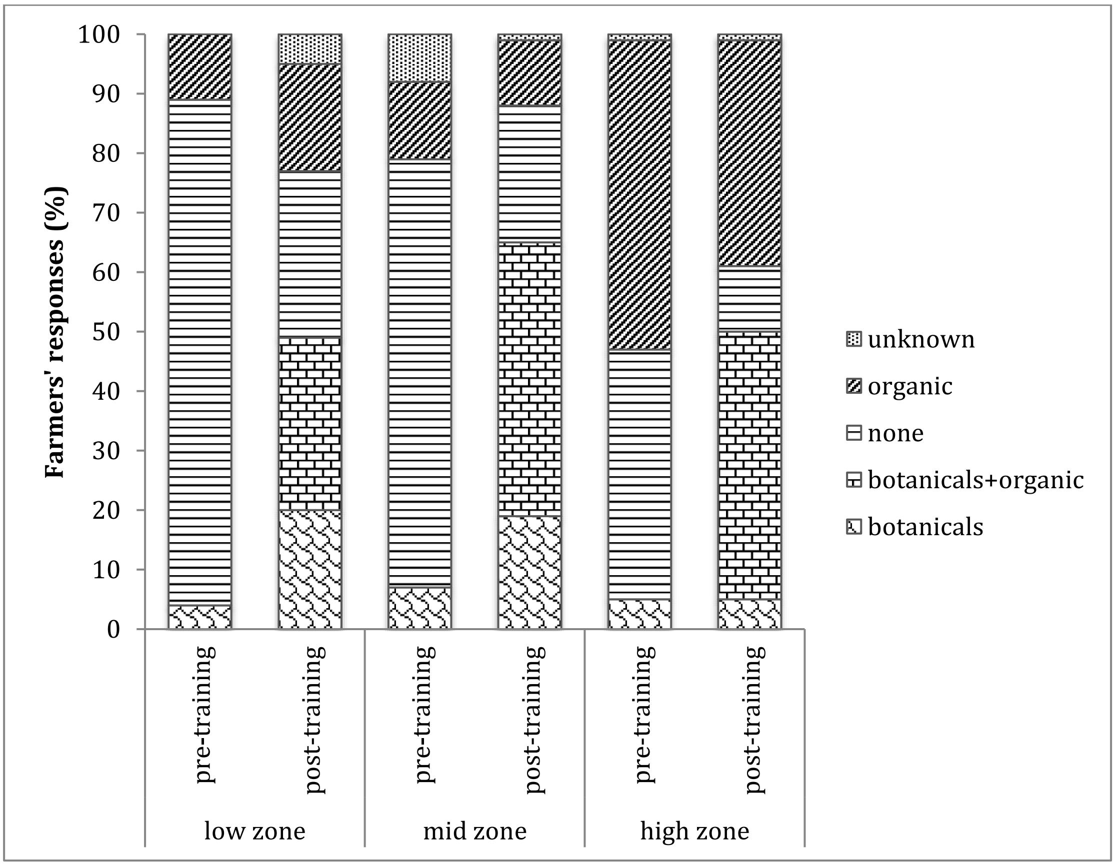


Fig 4. Revised



100
90
80
70
60
50
40
30
20
10
0
Farmers' responses (%)
unknown
organic
none
botanicals+organic
botanicals
pre-training
post-training
pre-training
post-training
pre-training
post-training
low zone
mid zone
high zone

Table 1

Farmers' ability to recognize and identify common pollinators from photographs and specimens, before and one year after training activities, presented in percentages according to the three elevation zones. PT = Pre-training and AT= After training.

Farmers' responses	Honeybee						Hoverfly						Solitary bee					
	low		mid		high		low		mid		high		low		mid		high	
	PT	AT	PT	AT	PT	AT	PT	AT	PT	AT	PT	AT	PT	AT	PT	AT	PT	AT
correct	66	100	84	98	79	99	11	36	3	52	1	74	0	73	0	59	0	55
incorrect	9	0	2	0	5	1	19	39	19	22	8	24	2	16	5	32	0	30
unknown	25	0	14	2	16	0	70	25	78	26	91	2	98	11	95	9	100	15

Table 2

Farmers' ability to articulate the importance of three different pollinator groups in bean production, before and after training activities had taken place, and presented in percentages according to the three elevation zones. Hoverflies are also a natural enemy (NE). PT = Pre-training and AT= After training.

Farmers' responses	**Honeybee importance**						**Hoverfly importance**						**Solitary bee importance**					
	low		**mid**		**high**		**low**		**mid**		**high**		**low**		**mid**		**high**	
	PT	**AT**	**PT**	**AT**	**PT**	**AT**	**PT**	**AT**	**PT**	**AT**	**PT**	**AT**	**PT**	**AT**	**PT**	**AT**	**PT**	**AT**
pollinator	53	95	56	92	45	98	14	24	7	18	1	33	0	52	0	65	0	63
pest	16	2	11	4	16	1	14	14	17	9	10	12	1	9	1	3	1	4
NE	0	0	0	0	0	0	0	18	0	12	0	20	0	0	0	0	0	0
Pollinator +NE	0	0	0	0	0	0	0	22	0	33	0	27	0	0	0	0	0	0
unknown	31	3	33	4	39	1	72	22	76	28	89	8	99	39	99	32	99	33