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BEE POLLINATION UNDER ORGANIC AND CONVENTIONAL FARMING SYSTEMS : A REVIEW

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ABSTRACT : Pollination is the process in which pollen is transferred to the female reproductive organs of the plants thereby enabling fertilization and reproduction. Pollinators plays efficient role in pollination of wild plants and several crop species. Seventy-five percent of the crops grown for human consumption rely on pollinators, predominantly bees, for a successful harvest. However, over the last decade, both native and honey bee populations have been declining at alarming rates, raising concerns about the impact on crop pollination and global food security. To complicate the situation, many of the factors linked to bee population decline are the direct result of commonly adapted agricultural practices. . Fortunately, one of the simplest ways to conserve pollinators' population in an agriculturally reliant world is through organic farming. There are several studies citing the beneficial aspects of organic farming in this regard. In view of the important role of pollinators in global food security, it is necessary to conduct a critical study on the aspects directly related to the protection of health of pollinators.

Key words : Bee pollination, organic farming, conventional farming, pollinator health.

INTRODUCTION

Pollination is the process in which pollen is transferred to the female reproductive organs of the plants thereby enabling fertilization and reproduction. It is most important because it leads to the formation of fruits and seeds, continuing the life cycle of plants. Seventy-five percent of the crops grown for human consumption rely on pollinators, predominantly bees, for a successful harvest (Tracy and Jessica, 2015). Bees alone are responsible for about 80 per cent to 100 per cent of the pollination of crops, especially those related to the production of seeds and fruits (Rosemeire *et al*, 2009).

Pollination is an important phenomenon in agricultural systems especially in growing fruits and seed production which depend greatly on bees visiting during blossom. The major pollinator dependent crops are fruit and vegetable crops, spices and plantation crops, pulses, oilseeds etc. It has been estimated that the total annual economic value of crop pollination worldwide is about • 153 billion (Euro) (Gallai *et al*, 2009). Klein *et al* (2007) found that 87 of the world's leading food crops depend upon animal pollination, representing 35 percent of global food production. The area covered by pollinator-dependent crops has increased by more than 300 percent during the past 50 years (Aizen and Harder, 2009).

Many crop and wild plant species are partially or completely self-incompatible as they cannot produce fruit or seed without cross-pollination. It is not just self-incompatible plants that benefit from cross-pollination, but self-fertile varieties also produce better quality fruit and seeds on getting cross pollinated (Free, 1993). Cross pollination is facilitated by various agencies which may be animals (zoophily), most of them insects (entomophily), wind (anemophily - especially in grasses) and water (hydrophily - mainly in submerged water plants) (Thakur, 2012).

Insect and other organisms play major role in boosting agricultural production by significantly increasing the yields of crops, vegetables, fruits and seeds through visiting flowers and helping in pollination. Self-incompatible and cross-pollinated crops require pollinating service of efficient pollinators. Self-pollinated crops also benefit from insect pollination, that increase yield up to 30% from pollinator visits and also collection of nectar or pollen and benefit farmers from pollinators' service. Lack of pollinators causes decline in fruit and seed production. The self-pollinated crop species occupy less than 15% and the remaining are cross-pollinated crops that need help of pollinating agents, wind, water or insects for fertilization. Some crops also exhibit often cross pollinated nature. The genetic architecture of such crops is intermediate between self- and cross-pollinated species. The self-pollinated crop species also benefit from cross pollination and hybrids grown these days require pollination in order to bear satisfactory marketable crops. Some plants may carry thousands of flowers, but unless there is adequate pollination, little if any fruit will be produced. Pollination is one of the most important factors in fruit production (Partap, 2001).

Among the total pollination activities, over 80 per cent are performed by insects. Honeybees are however critically important for crop pollination worldwide (Levin and Waller, 1989; Watanabe, 1994; Thapa, 2006; Klein *et al*, 2007) and the yields of some fruit, seed and nut crops can decrease by more than 90 per cent without these pollinators (Southwick and Southwick, 1992).

Bees are estimated to pollinate 16% of the total of 0.25 million flowering plant species known so far. One-third of human diet is said to be derived from products of bee pollination. About 90 per cent of the world's plant food production is mainly based on 82 products derived mainly from only 63 plant species. The importance of bees can be realized from the fact that for 39 of these plant species bees are the major pollinators (Thakur, 2012).

About one-third of the total human diet comes from bee pollinated crops and pollination value worth about 143 times than honey production. The wide diversities of honeybee and flowering plant species occurring in the country help to maintain diversity of flora and bee fauna greatly influence crop pollination and reward hive production in the service of nature and human beings as well. The pollinating potential of a single honeybee colony becomes evident when it is realized that bees make up to four million trips per year and that during each trip an average of about 100 flowers are visited (Thapa, 2006).

Highest per cent increase in yield by bee pollination over self pollination in sunflower was recorded to be 68-78 per cent followed by *Citrus spp.* which recorded 35-67 per cent increase in yield. Crops like rapeseed, toria, niger and pigeon pea recorded 26-31, 20-48, 24-42 and 21-30 per cent increase in yield respectively (Kumar and Agarwal, 2012). Bees provide a disproportionately large share of pollination services, valued at a total of $16 billion per year in the United States. Of this total, $12.4 billion are attributed by honey bees and $4 billion by native bees and other insects (Calderone, 2012). While many of the most commonly produced crops such as rice, wheat and corn are pollinated by wind, the majority of fruits, vegetables, and nuts — which are of high economic value and supply humans with the vast majority of vitamins and minerals — typically rely on bees for pollination. A few of the important crops relying on insect pollination to produce fruit include apples, avocados, blueberries, cran-berries, and cherries (Tracy and Jessica, 2015).

Several studies have stressed the importance of honeybees for fruit and seed yields in different crops and cultivars like Assam lemon *Citrus limon* (L.) Burm. (Gogoi *et al*, 2007), pear *Pyrus communis* L., apple *Malus domestica* Borkh., Japanese plum *Prunus salicina* L., (Stern *et al*, 2007) and rabbit eye blueberry *Vaccinium ashei* Reade (Dedej and Delaplane, 2003).

Bees pollinate almost all crops and very few crops are dependent on other insect species for their pollination requirements. Self-incompatible and cross-pollinated crops require efficient pollination services of honeybees and other pollinators. Even self-pollinated crops benefit from insect pollination because thus pollinated crops produce higher yields with good quality seeds. Thus, honeybees are unquestionably the primary pollinating agents of many crop plants (Thapa, 2006).

Honey bees have been reported as major pollinators in crops like alfalfa (Tasei, 1972; Ahmed *et al,* 1989), allspice (Chapman, 1966), almond (Tufts, 1919), apple (Kurennoi, 1969), apricot (Kobayashi, 1970), asparagus (Jones and Robines ,1928), banana (Mahadevan and Chandy, 1959), betel nut (Murthy, 1977), bitter gourd (Grewal and Sidhu, 1978), bottle gourd (Alam and Qadir, 1986), cardamom (Verma, 1987), carrot (Hawthorn *et al*, 1960), cashew nut (Phoon *et al*, 1984), castor (Alex, 1957), cauliflower and cluster bean (Free, 1993), chickpea (Howard *et al*, 1916), chilli (Tanksley, 1985), chrysanthemum (Smith, 1958), cinnamon (Purseglove, 1968), clove (Wit, 1969), coconut (Sholdt and Mitchell, 1967), coffee (Nogueira-Neto *et al*, 1959), coriander (Shelar and Suryanarayana, 1981) etc.

However, over the last decade, both native and honey bee populations have been declining at alarming rates, raising concerns about the impact on crop pollination and global food security. To complicate the situation, many of the factors linked to bee population decline are the direct result of commonly adapted agricultural practices. Chemical intensive agricultural production has been implicated as a major source of threats to pollinators. Fortunately, one of the simplest ways to conserve pollinators' population in an agriculturally reliant world is through organic farming. Organic farming not only prohibits the use of pesticides which are highly toxic to bees and persistent in the environment, but also require that organic producers manage their farms in a manner that fosters biodiversity and improves natural resources.

Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved (IFOAM, 2008). A number of studies have demonstrated that organic farms support more pollinators than conventional farms (Kremen *et al*, 2002; Andersson, 2014; Kehinde and Samways, 2014). Organic farming requirements prohibit the use of toxic pesticides; support higher levels of biodiversity than conven-tional farms, and can contribute to pollinator conservation in a number of ways.

Conventional farming, also known as industrial agriculture, refers to farming systems which include the use of synthetic chemical fertilizers, pesticides, herbicides and other continual inputs, genetically modified organisms, Concentrated Animal Feeding Operations, heavy irrigation, intensive tillage, or concentrated monoculture production. Thus, conventional agriculture is typically highly resource and energy intensive, but also highly productive. Bee exposure to chemical pesticides has been widely implicated as a leading factor in both declining domestic honey bee and native bee populations. Exposure to agricultural insecticides is one of the primary ways in which bees come in contact with toxic chemicals, but herbicides, fungicides and acaricides (pesticides used to treat honey bee hives infected with parasitic mites) may also have negative effects on bee health (Johnson, 2010; Mullin, 2010). However, the honey bee visitation to sunflower field was unaffected by seed treatment with insecticides for managing sucking pests of sunflower (Kencharaddi *et al*, 2012).

The assessment of organic farming relative to conventional farming in the four major areas of sustainability *viz*., area of production, environmental sustainability, economic sustainability and area of well being, with the level of performance of specific sustainability metrics representing 25, 50, 75 and 100%, organic farming systems balance better in the four areas of sustainability compared to conventional farming systems (Reganold and Watcher, 2016).

Bee Pollination in organic v/s conventional farming systems in field crops

The most essential staple food crops on the planet like corn, wheat, rice, soybeans and sorghum need no insect help at all as they are self or wind pollinated. However, it is not just self-incompatible plants that benefit from cross-pollination, but self-fertile varieties also produce better quality fruit and seeds on getting cross pollinated (Free, 1993). The vitality of *Bombus impatiens* colonies after exposure to corn (*Zea mays*) fields grown from neonicotinoid treated seed (conventional) and untreated seed (organic certified) during pollen shed exhibited significantly more workers in organic sites compared to conventional sites. Multi-hives placed in organic fields also had a higher mean weight of drones in comparision to conventional sites (Kelly, 2014). This might probably due to the fact that in agricultural crop-land, bumble bees tend to rely heavily on hedgerows for adequate forage resources, as there is usually a wider diversity of flowers than within crop fields (Morandin and Kremen, 2013).

The working out of pollination deficit (the difference between potential and actual pollination) and bee abundance in organic, conventional, and herbicide-resistant, genetically modified (GM) canola fields (*Brassica napus* and *B. rapa*) in northern Alberta, Canada resulted in finding no pollination deficit in organic fields, a moderate pollination deficit in conventional fields, and the greatest pollination deficit in GM fields. Bee abundance was greatest in organic fields, followed by conventional fields, and lowest in GM fields. Overall, there was a strong, positive relationship between bee abundance at sampling locations and reduced pollination deficits. Seed set in *B. napus* increased with greater bee abundance (Morandin and Winston, 2005). A survey was conducted very recently to record flower visitors in insecticide sprayed and non-sprayed mustard crops. The insect flower visitors in non-sprayed mustard field were recorded over three times higher (19 insects species) than those in sprayed field (6 insects species only). It is clear that pesticide spray has been one of the various factors for pollinators decline. Therefore, it is essential to survey and collect insect species in various crop plants during their flowering periods, identify and conserve them, and explore their potentiality as crop pollinators (Thapa, 2006)

The plant species number of the pollination types (i.e. insect pollination versus non-insect pollination) were much higher in organic than in conventional fields and higher in the field edge than in the field centre when arable weed communities were compared with respect to the type of pollination in the edges and centres of 20 organic and 20 conventional wheat fields. The comparison between the proportions of both pollination types to all plant species revealed that the relative number of insect pollinated species was higher in organic than in conventional fields and higher at the field edge than in the field centre, whereas the relative number of non-insect pollinated species was higher in conventional fields and in the field centre. It also showed that insect pollinated plants benefit excessively from organic farming, which appeared to be related to higher pollinator densities in organic fields (Doreen and Teja, 2006).

The species richness of bees and the number of brood cells of total bees of the red mason bee *Osmia rufa* and of other bees were positively related to the proportion of non-crop habitats (landscape composition), but not to edge density (landscape configuration). The landscape effect was independent of farming system and habitat type. A doubling of non-crop habitats from 30% to 60% in a landscape circle with 500 m radius resulted in an increase of total bee brood cells of more than 100%. The species richness of bees was higher in organic than in conventional sites (fallow strips and field centres), and higher in fallow strips than in field centres. For the most abundant bee species *O. rufa*, organic farming enhanced the number of brood cells significantly, resulting in 30% more brood cells in organic than in conventional fields and 107% more brood cells in fallow strips adjacent to organic than in fallow strips adjacent to conventional fields. For other bees, the number of brood cells was marginally higher in fallow strips than in field centres. The total number of bee brood cells was marginally enhanced by organic farming and in fallow strips (Andrea *et al,* 2010). Landscape configuration and composition affects trap nesting wasps and bees in both habitat types and both farming systems similarly. In studies on flower-visiting bees landscape and local factors were found to interact with each other: diversity decreased with decreasing landscape heterogeneity in conventional fields, but not in organic fields, indicating that organic fields compensated for lacking non-crop foraging habitats in homogeneous landscapes (Holzschuh *et al*, 2007; Rundlof *et al*, 2008). The positive effect of organic compared to conventional farming underlines the impact of local food availability on nest colonization) and reveal the potential importance of cereal fields in providing those food resources (Tscharntke *et al*, 1998).

Bee species richness was lower in the conventional cotton farm (five species in 20 h of sampling) than the organic farm (18 species in 18 h of sampling) in addition to lower relative abundance of each species (individuals/hour) on the conventional farm than on the organic farm (Viviane *et al*, 2014). The contribution of a set of different pollinator species can be more advantageous for cotton production than that of just one species. Increases in yield provided by bee species richness have been found in coffee (De Marco and Coelho, 2004), almond trees (Brittain *et al*., 2013) and many different crops (Garibaldi *et al*, 2013). Several bee species present near natural vegetation can benefit yield from functional complementarity of different species, with different body sizes and foraging behaviours (Blüthgen & Klein, 2011). In cotton flowers, different behaviours carried out by different flower visitors can increase crosspollination and self-pollination (Silva, 2007; Pires, 2009) and result in increased production. It also seems that a bee-friendlier environment, including natural-vegetation strips, diversification of cultivated crops and organic management practices, is important for maintaining higher bee populations and a richer bee assemblage on cotton flowers, as compared to the conventional farm (Kremen *et al*, 2007; Ricketts *et al*, 2008). Niger crop was introduced to enhance the honeybee activity and ultimately to increase the seed setting in sunflower. The experiments conducted over two years indicated that significantly higher seed equivalent yield of sunflower (849 kg/ha) was recorded in the intercropping system of sunflower + niger in 12:3 row proportion as compared to sole crop of sunflower (747 kg/ha). The honeybee activity was more when niger was intercropped as compared to the control treatment (Gaddanakeri *et al*, 2008).

Bee Pollination in organic v/s conventional farming systems in horticultural crops

Bee pollination results in a higher number of fruits, berries or seeds which may result in a better quality of the produce. The efficient pollination of flowers may also serve to protect the crops against pests. The value of bee pollination in horticultural crops in Western Europe is estimated to be 30-50 times the value of honey and wax harvests in this region. In Africa, bee pollination in horticultural crops is sometimes estimated to be 100 times the value of the honey harvest, depending on the type of the crop (Kevin, 2015).

The diversity of insect flower visitors in organic cashew ecosystem attracted by nectar rewards was great, but only a few species were common (*Apis mellifera* and *Ligyra* sp.) (Heard *et al*, 1990). Halictid bees (*Pseudapis oxybeloides* Smith), *Lasioglossum* sp. and one unidentified species, mainly collected pollen and occasionally fed on nectar of cashew panicles. Among halictid bees, *P. oxybeloides* was the most prominent and very active. Under field condition, a maximum of 53.6 per cent of hermaphrodite flowers were pollinated while the remaining hermaphrodite flowers were unpollinated on the evening of the same day of anthesis (Sundararaju, 2000).

The studies on the diversity of pollinators visiting cashew panicles under organic ecosystem revealed that panicles were visited by twenty seven species of pollinators. Among these, fifteen species belonged to the order Hymenoptera, nine belonged to Lepidoptera and two belonged to the order Diptera. In Hymenoptera, honeybees were the most dominant pollinators. *A. cerana* was the dominant pollinator among honeybees with a relative abundance of 34.46 per cent followed by *A. dorsata* (28.09%) and *A. florea* (21.33%) (Anjan Kumar Naik *et al*, 2015).

Mango flowers in conventional and organic system were visited by 21 species of insects belonging to the orders: Diptera, Hymenoptera, Lepidoptera and Odonata. Nectar was the foraged floral resource by all visitors, except for *A. mellifera,* who visited the flowers to collect nectar and pollen. In the organic farming, it was found that the number of Hymenopteran species were superior to conventional farming. *A. mellifera* was the most frequent accounting for 68.30 per cent of total visits in organic farming and 45.60 per cent in conventional farming. *Belvosia bicincta* (Diptera: Tachinidae) was the most frequent in conventional farming (17.70%), while the *Musca domestica* (Diptera: Muscidae) (10.27%) was the most frequent in organic farming. In addition, in conventional farming, there was concentration of bee visits in the morning, with gradual reduction during afternoon. The peak visitation was recorded between 8:30 a.m. and 11:30. In the organic farming, there were two visits peaks, one early in the morning (7:30 am to 8:30 a.m.) and another in the early afternoon (14:30 to 15:30), observing a quantitative balance in relation to the other zones. There were greater number of visits in organic farming, and this difference can be attributed to the absence of agrochemical application in organic area (Siqueira *et al*, 2008). Thus, the applications of agrochemicals interfere not only in the diversity of visitors, as well as the frequency of visitation. The application of agrochemicals affects the activity of pollinators and consequently the production of fruit (Singh, 1989; Jyothi, 1994). Thus, the management of culture, the application of pesticides should be avoided at peak flowering and, if necessary, that they are applied in the evening when there is less frequent visits, or at night.

In order to understand the implications of agriculture on the environment, ecosystem health must be measured. Observing the presence of a biological indicator within an ecosystem is one among them. In one such study, male euglossine bees were observed using as attractant cineole 1:8, at adjacent organic (La Paz) and conventional (La Carena) coffee farms near the Northern Barranca River, San Ramón, Alajuela, Costa Rica The total accumulated numbers of observed euglossine bee during the late-dry season (April 2004) were the same. However, in both studies during the wet season (June 2004 and August 2004), a higher number of bees was observed in the organic as compared to the conventional farm. The highest cumulative number of bees was observed within the organic farm during mid-wet season. This indicated that orchid bees are a viable bio-indicator of organic farm health on a seasonal basis (Ingemar *et al*, 2006).

Kenyan *Coffea arabica* L. is globally recognised for its high quality and it is used to blend other coffees in the world market. Assessment of the diversity of bee pollinators of coffee in organic and conventional farming system in Kiambu Kenya was reported by Rebecca *et al* (2011). Sixty three bee species were sampled with organic farm having 60 species and conventional farm 24 species. The Organic farm registered 95.2% (60 species) and the conventional farm 24 species, which is 38.1% of the total number of species. The organic farm had 59% of the total specimens collected. Bee abundance and diversity between the two farms were significantly different Bee abundance and diversity between organic and conventional farms differed significantly. *Andrena* (sp.) possibly a new species was collected. Thus wild bees other than *A. mellifera* are important pollinators of coffee. The wild bees were few in numbers and ways of enhancing their populations should be devised. In terms of bee species richness per family, Halictidae had the highest number of species (39%) followed by Apidae (33%). The lowest number of species was from Family Andrenidae and Colletidae each with 3% of the total number of species. Both Colletidae and Andrenidae were absent in the conventional farm. *A. mellifera* was the most abundant bee species in the sample area and it formed 72.6% of the total bee collection from the two farms (Rebecca *et al,* 2011). Organic farming was found to favour bee abundance and diversity. Conventional farming system may impact on bee diversity due to poisoning by agro-chemicals and lack of other plants that can serve as alternative floral resources and source of refuge when the main crop has been sprayed with agro-chemicals. A higher bee diversity, flower cover and diversity of flowering plants were recorded in organic compared to conventional farms (Holzschuh *et al*, 2007). There are also reports which show that the most serious threat to pollinators in agro ecosystems is poisoning from pesticides (Tew, 1998; Marshall *et al,* 2006).

Pollination, measured on organic and conventional farms of *Crataegus monogyna* hawthorn (Rosaceae) resulted in a total of 504 bees (439 bumblebees, 57 honeybees and 8 solitary bees) from five bumblebee species, one honeybee species and three solitary bee species. Bee abundance was significantly higher on organic farms than conventional ones and independent of farming system, bee abundance was significantly lower in field centres compared with edges, the pattern of which was more pronounced in conventional farms. Bee abundance was positively related to floral abundance, which was higher on organic farms and particularly high in organic field centres compared with conventional centres. Fruit set of hawthorn was significantly higher on organic compared with conventional farms for both open pollinated and supplementally pollinated flowers. *C. monogyna* flowers were found to be pollen limited (supplemental fruit set > open fruit set) on organic farms but not on conventional farms (Eileen and Jane, 2011).

The pollination of watermelon on farms that varied in the level of agricultural intensification along two axes: farm management type (organic versus conventional) and isolation from large areas of oak woodland and chaparral habitat (near versus far) wherein near sites (N) contained 30% natural habitat within a 1-km radius of the farm and far sites (F) had 1% natural habitat within a 1-km radius was studied. From least to most intensive management, farms were therefore classified as organic near (ON), organic far (OF) and conventional far (CF); no conventional near farms occurred in the study area. Honey bees were not sufficiently abundant on organic farms, however, to provide the full pollination service; thus, organic farms, both near and far from wild land areas, relied in part on native bee where native bees could not provide sufficient pollination services, farmers routinely rented honey bee colonies to obtain adequate pollination. On organic farms near natural habitat, the native bee communities provide full pollination services even for a crop with heavy pollination requirements without the intervention of managed honey bees. On these farms, all the functional pollinator specie *Halictus tripartitus*, *Bombus californicus*, *Peponapis pruinosa*, *Bombus vosnesenskii*, *Melissodes lupine*, *H. farinosus*, *Lasioglossum* spp., *Dialictus* spp., *H. ligatus, L. mellipes, Hylaeus rudebeckiae* and *Agapostemon texanus* deposited pollens on watermelon whereas only six among these were found to pollinate under other two farming systems. All other farms experienced greatly reduced diversity and abundance of native bees, resulting in insufficient pollination services from native bees alone (Claire *et al*, 2012).

Lethal effects of insecticides to bees are attributed to many pesticides which are acutely toxic to bees and result in death. Carbamates, organophosphates, synthetic pyrethroids, chlorinated cylcodienes and neonicotinoids are highly toxic to bees. Sublethal effects refers to pesticide levels that do not kill bees at significant rates may nonetheless have effects on performance that inhibit tasks such as olfactory learning, foraging and reproduction, which affects hive survival. Often pesticides have more toxic effects in combination than alone exhibiting synergistic effects. In addition, herbicides used in fields, along rights-of-way and in forests tend to reduce the number of flowering plants. This reduces the amount of food available for native pollinators, making their survival more difficult. This has effects throughout the food chain, as reduced pollination leads to reduced fruit on which birds and other creatures depend (Anon, 2003).

Among different insecticide formulations, dust formulation of insecticide is most toxic to bees followed by wettable powder, flowable, emulsifiable concentrate, soluble powder and solution whereas the least toxic formulation to bees is granules (Johansen and Mayer, 1990). The most toxic insecticides to honey bees based on relative toxicity of insecticides are thiamethoxam, fipronil, imidacloprid, clothianidine and deltamethrin with least LD 50 values of 5.0, 4.2, 3.7, 2.5 and 2.5 respectively (Bonmatin *et al,* 2004).

The exposure to dry spray residues of each of the surface-applied, non systemic insecticides chlorpyrifos, carbaryl and cyfluthrin adversely affected colony vitality of bumble bees. Fewer worker bees, honey pots, and brood chambers were present in hives from treated plots. Worker biomass and colony weights were also reduced. For both carbaryl- and chlorpyrifos-treated plots, two of the four colonies had no live brood or adults. Colonies from chlorpyrifos-treated plots had significantly less brood than from carbaryl- or cyfluthrin-treated plots. Colonies from carbaryl-treated plots had less brood than those exposed to cyfluthrin. There also was reduced foraging activity on treated plots (Jerome *et al*, 2002). Pollen (bee bread and trapped pollen) and wax was analysed for pesticide residues among which a significant number of samples analyzed were from operations impacted by Colony Collapse Disorder (CCD) and control operations (not impacted by CCD). Additional samples were from honey bee colonies placed in Pennsylvania apple orchards where pesticide applications over the past 7 years have been well documented. The third source was from beekeepers, which trapped pollen while their bees were in specific cropping situations or who were concerned about the declining health of their colonies. In a total of 108 pollen samples analyzed, 46 different pesticides including six of their metabolites were identified. Up to 17 different pesticides were found in a single sample. Samples contained an average of 5 different pesticide residues each. Only three of the 108 pollen samples had no detectable pesticides (Frazier *et al,* 2008).

Organic as a solution

A number of studies have demonstrated that organic farms support more pollinators than conventional farms. Organic farming requirements prohibit the use of toxic pesticides, support higher levels of biodiversity than conventional farms and can contribute to pollinator conservation in a number of ways. Additionally, USDA's National Organic Program specifically ensures that organic farming supports the health of our pollinators in the following four key ways:

1. Exposure to toxic chemicals

One of the biggest threats to bee health is exposure to toxic chemicals. Bees are exposed to numerous chemicals through a variety of routes. Neonicotinoids exposure most frequently occurs when bees consume pollen and nectar from crops grown using neonicotinoid coated seeds or from dust created by pesticide coated seeds during planting.. Organic farming directly addresses these issues and supports pollinator health by reducing bee exposure to toxic chem-icals. Organic farmers are prohibited from using synthetic substances as a general rule, and must use integrated pest management (IPM) techniques to control pests instead of relying solely on pesticides. The use of IPM techniques is mandated by organic regulations at 7 CFR 205.206, requiring organic producers to develop and implement a preventive pest management program before any pest control materi-als are used. Only after these preventive practices have failed is an organic farmer allowed to use allowed non-synthetic pest management products. Additionally, organic producers are prohibited from using seeds treated with toxic pesticides, even when they cannot find a particular seed in organic form and are allowed to use a conventional version of the seed. At no time may an organic producer plant a seed that has been treated with prohibited synthetic pesticides. By maintaining an agricultural landscape that supports beneficial insects which feed on pests, organic farmers reduce the number and quantity of pesticides nec-essary to protect their crops. When they do use pesticides, these are less toxic and persist in the environment for a shorter amount of time than most synthetic pesticides.

2. Pollinator habitat and landscape biodiversity

Lack of habitat and nutritional food sources are also important factors in pollinator decline. Native bees rely on undisturbed patches of native habitat as well as habitat 'corridors' which enable them to travel between patches. Additionally, both native and domesticated honey bees need a diversity of nutritious plants where they can collect sufficient pollen and nectar to support the hive. Organic farming supports pollinator health by providing a more diverse landscape that affords more abundant and higher-quality food and habitat to both native and managed bees. Organic farms are required to manage their opera-tions in a manner that "maintains or improves the natural resources of the operation" [7 CFR 205.200], which include the health of pollinators. Farmers meet this requirement by implementing techniques such as crop rotations, cover crops, and multi-functional insectary hedge rows which provide foraging bees a more diverse array of nutritious plants from which to collect pollen and nectar. Additionally, organic farms tend to support more native wild plants than conventional farms.

3. Exponential benefit

While we understand that increasing pollinator habitat and food sources on any farm is going to be better than nothing, reducing pesticide usage and increasing habitat heterogeneity at the same time have a compounding effect in benefiting pollinators. Anderson *et al* (2014) found that pollinator services to crops on organic farms increased when habitat heterogeneity was increased. Surprisingly, this same trend was not seen on conventionally farmed land. The study authors suspect this likely occurred simply because the lack of synthetic fertilizers and pesticides make organic farms more pollinator friendly. By increasing habitat and food sources available to bees in ag-ricultural landscapes while reducing the applications of toxic chemicals (practices that are federally regulated requirements of organic certification), organic farms can increase the health of our pollinators and in turn, help improve food security.

4. Organic apiculture

The National Organic Standards Board (NOSB) in 2010 re-leased recommendations for developing organic apiculture, and USDA has announced it will release draft standards for organic apiculture this year. Until these new standards are passed, organic beekeepers are operating under livestock standards. Current regulations for organic livestock do not al-low the use of synthetic pesticides, a requirement that carries over to hive management. It is anticipated that the new stan-dards will additionally bolster efforts to reduce bee exposure to pesticides by establishing forage and surveillance zones (Tracy and Jessica, 2015).

CONCLUSION

Pollinators play a critical role in crop produc-tion around the world. Seventy-five percent of major crops grown for human consumption worldwide rely on insects for pollination. However, with the decline of the domestic honey bee as well as native bee populations, our food security is at risk. No single factor has been consistently attributed as the cause of honey bee population decline. Instead, a number of factors including exposure to toxic pesticides, parasite and pathogen infections, poor nutrition, and habitat loss likely interact together resulting in lethal consequences for bees. While there is no 'silver bullet' to restore the health of our pollinator populations, organic farming can be part of the solution. Organic farming supports pollinator health by using techniques that improve pollinator habitat, providing more diverse and nutritious forage options, and reducing the use of synthetic pesticides that are toxic to bees. Here, we review the science behind bee health, including basic pollination biology, threats to our pollinators and how organic farming benefits our pollinators.

While organic farming clearly provides the greatest benefit to our pollinator communities, it is not realistic to expect that the entire agricultural system completely change overnight. Fortunately, many of the pollinator-friendly tech-niques that organic farmers utilize can also be incorporated into conventional farming systems. By introducing plant heterogeneity into farming systems by way of crop rotations, hedge row planting, and by fostering native plant diversity within and around farmland, any farm can combat pollinator malnutrition and habitat degradation. Additionally, the incorporation of integrated pest manage-ment techniques that encourage beneficial pest predators can help conventional farmers reduce the quantity of chemical pesticides used and, in turn, the level of bee exposure to pesti-cides. Finally, organic farming benefits all of agriculture simply by supporting healthier pollinator communities essential to nutritious food production regardless of farming method.

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