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Research Article

Indiscriminate use and inappropriate application of agrochemicals by smallholder farmers in Amhara Region, Ethiopia: Implications for sustainable beekeeping, crop and livestock production

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Abstract: *This study was conducted to investigate the knowledge gaps regarding the use of agrochemicals by the farming communities in the Amhara Region, Ethiopia and its impact on beekeeping, crop and livestock production. The primary data were collected through household surveys, key informant interviews, focus group discussions and researchers' observations. A total of 540 farmers (270 beekeepers and 270 non-beekeepers) were interviewed using a semi-structured questionnaire. The survey data was analyzed using SPSS software version 21, while the qualitative data was analyzed using content analysis. The results revealed that beekeeping contributes significantly to the livelihoods of smallholder farmers in the Amhara Region, mainly through the provision of hive products for home consumption and income but also for pollination services. The trends in the past decade showed that honeybee colony holdings and hive productivity had decreased due to indiscriminate use of agrochemicals, among others. Both beekeeper and non-beekeeper farmers in the study areas have been using different types of agrochemicals to control crop pests, diseases and weeds, and in some areas farmers used herbicides to clear weeds from pastureland. Farmers also stated that they are already aware of the negative effects of agrochemicals on honeybees. Nevertheless, the applications of agrochemicals are continuing without attitudinal changes. The results also showed that farmers purchase agrochemicals from legal as well as illegal vendors without proper understanding of their safe use and the expiry dates. Farmers' use of agrochemicals in violation of the technical recommendations on their proper applications; they ignore risks and safety instructions, use unsafe storage facilities, do not use protective devices when applying agrochemicals, and dispose of agrochemical containers unsafely. The findings demonstrated that apart from the direct effects on honeybees, indiscriminate and inappropriate application of agrochemicals even poses risks to the lives of farmers. Beekeepers, non-beekeepers and both crop and livestock experts revealed that* *nowadays IPM has not been used by farmers as an alternative to synthetic agrochemicals. Farmers are also unaware of the legal frameworks available to protect honeybees from the negative effects of agrochemicals, and they have not developed local bylaws that can be used by farming communities to protect honeybees from the negative effects of agrochemicals. The results also showed that the direct economic losses incurred due to the loss of honey bee colonies from the indiscriminate application of agrochemicals run into ETB 11,520,000.00 /USD422,133.00/. Thus, the indiscriminate use of agrochemicals has become one of the major threats to the development of beekeeping, crop and livestock production. Therefore, very strong actions are needed by concerned and responsible stakeholders to save the lives of honeybees. The interventions to reduce agrochemical exposure should be implemented through context-specific and integrated approaches.*

Keywords: Agrochemicals, Beekeepers, Honeybees, Non-beekeepers

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1. Introduction

In Ethiopia, beekeeping has significant contributions to improve the livelihoods of smallholder farmers as well as to the nation's economy. According to a MoARD (2007) report, Ethiopia has a production potential of 500,000 tons of honey and 50,000 tons of beeswax per annum. According to the FAO-STAT (2021) report, 53, 782 tons of honey and 5, 790 tons of beeswax was produced in 2021. Besides, beekeeping stabilizes and protects fragile environments and increases the production of crops through pollination services (Addi *et al*., 2006; Jacobs *et al*., 2006). These show that the contribution of beekeeping to poverty reduction, sustainable development and conservation of natural resources is very high.

The Amhara Region possesses over one million honeybee colonies and the annual estimated production of honey and beeswax constitutes more than 25% of the total national production (CSA, 2020). Beekeeping is a well-established practice in the farming communities of the region and it plays a significant role as a source of cash income from sales of bees' products such as honey and beeswax, providing nutrition, provisioning of pollination services, and generating rural employment opportunities. Despite the great potential, the sub-sector is gravely exposed to and unprotected from the negative effects of indiscriminate application of agrochemicals (Ejigu *et al*., 2009; Tassew and Wurzinger, 2016).

In developed countries, side effects of agrochemicals are known to cause disorder to the life of honeybee populations, apart from directly affecting the production of various bee products. At the global level, various interventions have been implemented to minimize the side effects of agrochemicals on honeybees (Greenpeace International, 2013). Over recent years the indiscriminate application of agrochemicals to boost crop productivity and production has increased in Ethiopia in general and in the Amhara Region in particular. This is because beekeeping is extensively practised in mixed farming systems and both beekeeper and non-beekeeper farmers have been using agrochemicals to boost crop productivity and production (Ejigu *et al*., 2009; Begna, 2015; Tassew and Wurzinger, 2016). Smallholder farmers also use agrochemicals to control weeds on pasture lands (Tassew and Wurzinger, 2016). Moreover, such controversial agrochemicals as DDT and Malathion have respectively been extensively applied to control malaria carrying mosquitoes around human settlements and to control the maize weevil in stored maize. Indeed, the overuse and misuse of agrochemicals result in the death of honeybee populations and contamination of bee products. Associated declines in density of bee colonies also cause a decline in crop production. Environmental contamination is also a growing concern. These effects in turn result in long- term biodiversity degradation, food insecurity and human health problems (FAO, 2019). These concerns are shared by farmers, development and research organizations, and policymakers. For instance, the national proclamation to regulate the application of agrochemicals that harm honeybees is old enough to be widely enforced. However, the enforcement guidelines are not yet put in place. This calls for collaborative efforts and actions among different stakeholders in the beekeeping subsector. Collective actions of key stakeholders are imperative, in order to properly utilize agrochemicals without affecting honeybee populations and other pollinator insects. Therefore, this study was carried out to investigate the knowledge gaps regarding the use of agrochemicals by the farming communities in the Amhara Region, Ethiopia and its impact on beekeeping, crop and livestock production.

2. Materials and Methods

2.1. Description of the study area

The Amhara National Regional State is one of the regional states in the Federal Democratic Republic of Ethiopia and extends from 9° to 13° 45'N and 36° to 40° 30'E. It covers approximately 161,828.4 km2 in area and is moderately compact in shape. It covers 11% of the country's total surface area, and consists of three major agro-ecological zones: the highlands (above 2,300 meters above sea level (masl)), the mid-lands (1,500 to 2,300 masl), and the lowlands (below 1,500 masl), which respectively account for 25%, 44%, and 31% of the region's total surface area (ANRS BoFED, 2011).

The region consists of 13 administrative zones categorized into Western Amhara (East Gojjam, West Gojjam, Awi, Bahir-Dar, South Gondar, Western Gondar, Central Gondar, and North Gondar Zones) and Eastern Amhara (Waghimra, North Wollo, South Wollo, Oromiya, and North Shewa Zones). These zones are divided into a total of 113 districts and 3,216 kebeles. The region's topography embraces plains, gorges, plateaus, hills, and mountains. The altitude ranges from as low as 500 meters to 4,620 meters at the peak of Ras Dashen Mountain. The study was carried out in 15 of the 113 districts, which were selected purposely based on their potential for beekeeping and crop production (Figure 1).

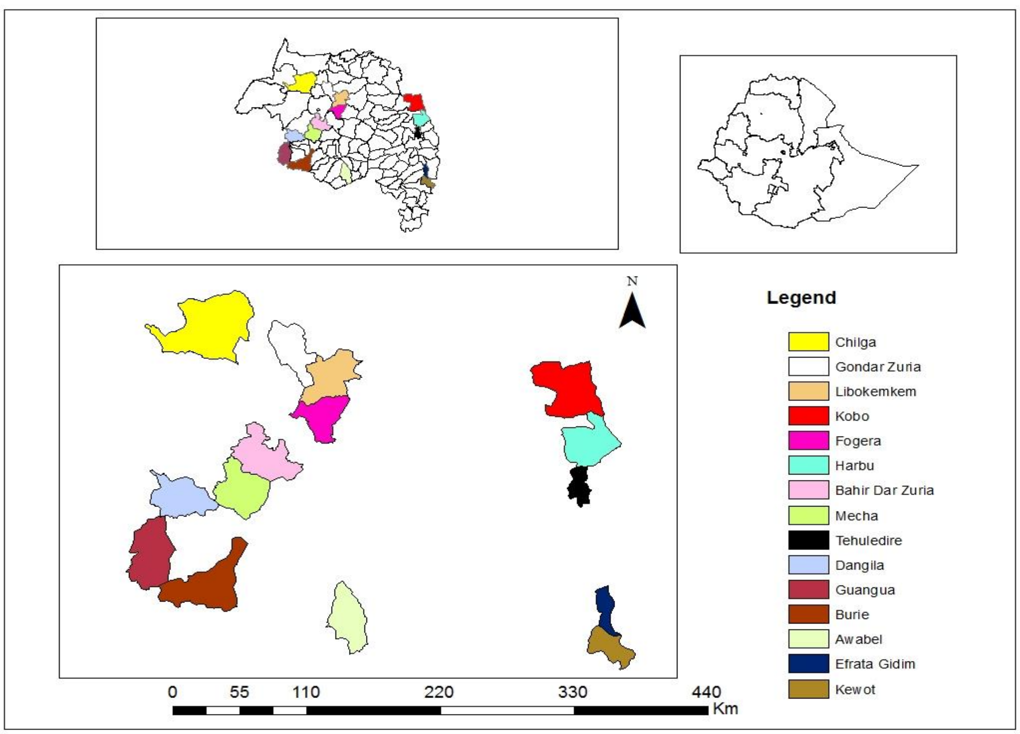

Figure 1: Map of the study areas
Source: Prepared by authors using Geographic Information System (GIS)

2.2. Methods of data collection

2.2.1. Primary data collection

The primary data were collected through household surveys, key informant interviews, focus group discussions and researchers' observations. At the first stage, nine districts (Awabel, Mecha, Dangila, Guangua, Bahir Dar Zuria, Fogera, Libokemkem, Gondar Zuria, and Chilga) were purposefully chosen based on greater potential for beekeeping and the existing widespread usage of agrochemicals. In the second stage, two rural Kebeles were chosen from each district using purposive sampling based on their relative beekeeping potential and existing high level of agrochemicals use in crop cultivation. The overall population was divided into two groups in the third stage: beekeepers and non-beekeepers. A total of 540 respondents (270 beekeepers and 270 non-beekeepers) were chosen at random and interviewed using semi-structured questionnaires. The questionnaire was pre-tested to ensure that it generated all of the necessary information to achieve the specified objectives, and it was fine-tuned after that. The data was collected between January 23 and September 18, 2018. Before conducting the survey, the researchers visited some sample villages and shops selling agrochemicals, as a result of which several issues related to the application of agrochemicals and beekeeping practices were learnt by observation and informal discussion with people. Transect walks created opportunities for observation and informal discussion with the people. The issues that emerged from observation and informal discussion were used to guide key informant interviews (KIIs) and focus group discussions (FGDs).

The KIIs were held with beekeeping expert researchers and livestock development practitioners (Table 1). Open-ended questions were used, and the interviews were done using the local language (Amharic). A voice recorder was used to record responses. The researchers conducted the interviews with the help of a research assistant.

A total of 36 FGDs was carried out by farmers, development practitioners, and researchers (Table 2). The aim of the focus groups was to obtain a better understanding of the issues discussed and to validate the survey findings. The discussions were guided by open-ended questions, and the discussions were conducted in the local language (Amharic). A voice recorder was used to record responses. The researchers conducted the discussions with the help of a research assistant.

Table 1: List of Key Informant Interviewees

Interviewees	Number
Livestock development agents	16
Head of Zone Livestock Resources Development and Promotion Office	8
Manager of Livestock Resources Development and Promotion Office, Amhara Region	1
Director of livestock research, Amhara Region	1
Beekeeping expert, Amhara Region	1
Beekeeping researcher, Andassa Livestock Research Center	1
Total	28

Table 2: List of focus group discussants

Focus group discussants	Number of FGDs
Farmers	16
Livestock experts working in District Office of Agriculture	9
Livestock experts working in Zone Office of Agriculture	5
Livestock experts working in Livestock Resources Development and Promotion Office, Amhara Region	1
Livestock researchers	1
Beekeeping researchers	1

Region crop extension experts	1
Bahir Dar Health Clinic experts	1
Plant Seed and Other Agricultural Inputs Quality Control Authority Experts	1
Total	36

2.2.2. Secondary data collection

Secondary data were collected from the Ministry of Agriculture, the Bureau of Agriculture, the Amhara Region, Livestock Resources and Development Promotion Office of Amhara Region, the Amhara Region Agricultural Research Institute (ARARI), zone and district offices of Agriculture, Amhara Region, as well as from published and unpublished literature.

2.3. Statistical analysis

The Statistical Package for the Social Sciences (SPSS) software programme, version 21, was used to analyze the survey data. The index calculation was used to rank the usage of beekeeping income and the various forms of beekeeping limitations. Content analysis was performed on the data obtained from KIIs and FGDs.

3. Results and Discussion

3.1. Demographic characteristics of the respondents

Of the total respondents, 98.7% and 97.4% of beekeepers and non-beekeepers were male-headed households. Similar findings were reported by several authors (Adebabay *et al*., 2008; Assemu *et al*., 2013; Dereje *et al*., 2016) who indicated that agricultural activities in general and beekeeping, in particular, are mainly duties of males, with females assigned to and engaged mainly in house duties.

The majority (87% of beekeepers and 88.9% of non-beekeepers) of the respondents was in the age range of 14–60 years old; indicating that age is not a limiting factor for beekeeping, and beekeeping is playing a greater role as a means of job and income generation. At the same time, the involvement of young people in the beekeeping activity is an opportunity for future expansion and development of the subsector, possibly as a sole business. The results concur with earlier findings (Tewodros *et al*., 2015; Dereje *et al*., 2016; Sintayehu and Tibebe, 2016), who stated that beekeeping practice is learnt through parental guidance between generations and is practiced by all economically active age groups (15–65 years old).

About a quarter of the beekeepers and one-third of non-beekeepers are literate, and achieved from basic to Grade 12 educational levels (Table 3). This shows that education levels in farming households should be considered in identifying problems in their agricultural activities and seeking appropriate solutions thereby improving productivity and production. Similarly, Adebabay *et al*. (2008) reported that educational level of farming households may have significant importance in identifying and determining the type of beekeeping development and extension services that should be provided.

Regarding family size, the beekeeper respondents had an average size of 5.53±1.5 persons per family, while the non-beekeepers had an average size of 5.82±1.76 (Table 3), which is in line with the national average of six persons per household.

3.2. Farming systems and land holding in the study area

In the mixed farming system, many farmers combine crop production, livestock production, and beekeeping in order to exploit the potential benefits from the different subsystems (Adebabay *et al*., 2008; Tassew and Wurzinger, 2016). Similarly, as indicated in Table 4, all the beekeeping and non-beekeeping respondents in the study areas practiced mixed farming (i.e., crop, livestock including beekeeping, and forestry), which they consider a means of risk aversion. In particular, as an integral part of the mixed farming system, beekeeping plays a substantial role in household food security in the study area. It can meet urgent financial needs, dietary requirements, and loan repayments and act as a buffer in the case of crop failure. It also serves social and cultural functions.

The average landholdings of both the beekeepers and non-beekeeping respondents are small and comparable (Table 5). At current levels of productivity per hectare, these average sizes of landholding are considered inadequate to produce sufficient agricultural products to sustain the livelihood of farmers. Therefore, the option of involvement of farmers in beekeeping activities can be considered one strategy to support their livelihoods, as beekeeping can be conducted in a very small area without competing for land with other agricultural activities.

Table 3: Demographic characteristics of the respondents

Variables		Beekeepers (n = 270)		Non-beekeepers (n = 270)	
		n	%	n	%
Sex	Male	267	98.9	263	97.4
	Female	3	1.1	7	2.6
Age	Below 14	0	0	0	0
	14–60	235	87	240	88.9
	>60	35	13	30	11.1
Education level	Illiterate	60	22.2	90	33.3
	Basic education	140	51.9	110	40.8
	Grade 1–4	40	14.8	50	18.5
	Grade 5–8	20	7.4	10	3.7
	Grade 9–12	10	3.7	10	3.7
Family size		5.53±1.5		5.82±1.76	

n = number of respondents

Table 4: Farming systems of the respondents

Farming systems	Beekeepers (n = 270)		Non-beekeepers (n = 270)	
	n	%	n	%
Livestock only	-	-	-	-
Crop only	-	-	-	-
Beekeeping only	-	-		
Livestock and crop	-	-	270	100
Livestock, crop and beekeeping	270	100	-	-

n = number of respondents

Table 5: Landholding of the respondents (Mean ± Standard Deviation (SD))

Landholding (ha)	Farming category	
	Beekeepers (n = 270)	Non-beekeepers (n = 270)
Crop land	1.43±1.27	1.48±1.31
Pasture land	0.24±0.15	0.22±0.13
Forest land	0.26±0.21	0.25±0.20

n = number of respondents

3.3. Purpose of beekeeping and use of income from beekeeping in the study area

In this study, beekeepers were found to generate cash incomes from the sale of hive products and honeybee colonies to fulfill their needs. The majority of the beekeeping respondents keep the honeybee colonies as an income and food source for their families (Table 6). As a matter of fact, beekeepers in the region practice beekeeping as an integral part of their mixed farming system. Like other farming communities, they obtain cash income from the sale of agricultural products. Beekeeping has been reported to be one of the agricultural activities that assist farmers in diversifying income sources and provide food such as honey for household consumption (Adebabay *et al*., 2008; Alemu, 2015; Begna, 2015).

As shown in Table 7, beekeepers used the income obtained from beekeeping primarily to buy crop inputs (fertilizer, seed) followed by farm animals, food grains, cloth, and for house building.

Table 6: Purpose of keeping honeybee colonies

Purpose	n	Percent
As income source	38	14
Home consumption	16	6
Both (as an income and home consumption)	216	80

n = number of respondents

Table 7: Reported use of the income obtained from beekeeping

Use of income from beekeeping for:	1st	2nd	3rd	4th	5th	Index	Overall rank
Purchase of crop inputs	180	60	30	0	0	0.35	1
Purchase of livestock	101	80	37	33	19	0.29	2
Purchase of food grains	44	31	23	59	13	0.16	3
Purchase of cloth	28	19	33	27	25	0.11	4
Building a house	24	8	20	20	33	0.08	5

3.4. Honeybee colony holdings and honey yield in the study area

From the perspective of the levels of technology and management practices used by the beekeepers, three beehive types were identified: traditional, transitional (top-bar hive), and modern (movable frame hive). The average size of honeybee colony holdings per household is 5.4 ±1.45, 1.8 ±1.22, and 2.6 ±1.35 in traditional, transitional and movable frame hives, respectively (Table 8). The respondents reported that the average honey yield obtained from traditional, transitional and movable frame hives is 5.73 ± 1.69, 11.4 ± 1.85, and 17.6 ± 1.95 kg per hive per year, respectively. The results of this study are comparable with the findings of other scholars (Alemayehu, 2010; Bekele, 2015; Zewdie, 2017).

Table 8: Honeybee colony holdings and honey yield (Mean ± SD)

Hive types	Number of honeybee colonies	Honey yield in kg/hive/year
Traditional	5.4 ±1.45	5.73 ± 1.69
Transitional (top-bar)	1.8 ±1.22	11.8 ± 1.85
Modern (movable frame)	2.6 ±1.35	17.6 ± 1.95

3.5. Beekeepers' perceptions of trends in honeybee colony holdings and productivity in the study area

The majority (84%) of the beekeepers stated that honeybee colony holdings and productivity have decreased over the past five years for various reasons (Figure 2). Indiscriminate use of agrochemicals, lack of floral resources, and burden of pests and predators are reported to be the major limiting factors (Table 9). On the other hand, 13% of the respondents think that honeybee colony holdings and productivity showed an increasing trend, while 3% of them felt it remained constant. Different scholars also reported that side effects of application of agrochemicals, scarcity of bee forages, and honeybee pests and predators are the major bottlenecks in beekeeping development in different parts of Ethiopia (Adebabay *et al*., 2008; Alemu, 2015; Tassew and Wurzinger, 2016; Zewdie, 2017).

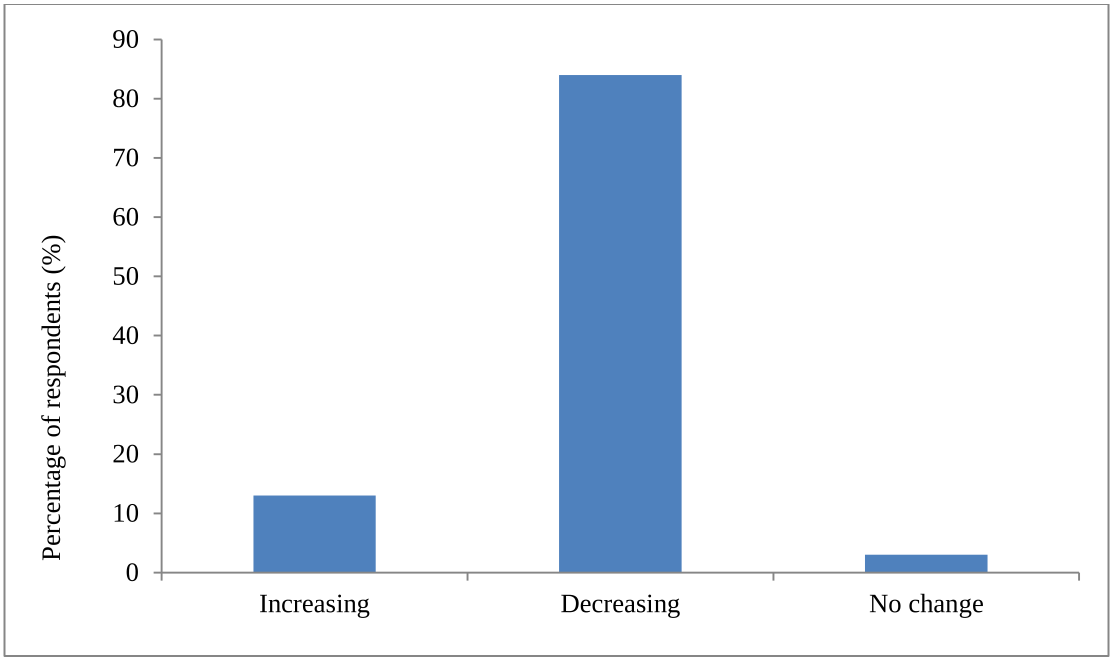

Figure 2: Percent respondents on the trends of honeybee colony holdings and productivity in the past five years

Table 9: Major reported reasons for the decrease in honeybee colony holdings and productivity

Reasons	1st	2nd	3rd	4th	5th	Index	Overall rank
Side effects of agrochemicals	223	47	0	0	0	0.37	1
Lack of floral resources	89	84	48	35	14	0.29	2
Pests and predators	34	51	26	39	9	0.15	3
Diseases	19	16	37	26	23	0.10	4
Drought	8	24	27	23	30	0.18	5

3.6. Use, application and handling of agrochemicals in the study area

Agrochemicals that are in use for crop protection were found to be the ones that kill honeybees. The majority of beekeepers and all non-beekeeper respondents confirmed that they use different types agrochemicals to control crop pests, diseases, and weeds (Table 10). Furthermore, a few farmers use of agrochemicals to control pasture land weeds. The researchers had a keen interest in knowing how far their colonies are from the crop and pasture lands. When asked, the majority of the respondents reported that they have crop and pasture lands within one km of the colonies. This is clearly within the potential foraging distance for honeybee colonies, as they fly two to three kilometers from their hive to find sources of food (nectar and pollen). Under such circumstances, undoubtedly the honeybee colonies could be potentially affected by agrochemicals applied in those crop and pasture fields.

3.6.1. Insecticides and fungicides used by farmers in the study area

With regard to insecticides and fungicides' use, beekeepers, non-beekeepers, and livestock and beekeeping development practitioners and researchers reported that various types of insecticides and fungicides are in use in farming systems (Table 11). They also mentioned that farmers spray the same or different types of insecticides repeatedly during the cropping season, without consulting their neighbours. The investigators have confirmed this by visiting some local insecticide and fungicide shops where different brands of insecticides and fungicides were sold (insecticides like Malathion, Dimethoate 40% EC, Perfecto 175 SC, Pritacet 10 EC, Ethiosulfan 35% EC, Gain 20 SL, and fungicides like

Agro-laxyl MZ-63.5 WP, Noble 25 WP, Mancozeb 80%WP, etc. are among the pictured ones). Photographs were taken of the products (Figure 4). Similar findings on different types of insecticides and fungicides were reported in the Amhara Region by several authors (Mengistu and Beyene, 2014; Alemu 2015; Begna, 2015; Tassew and Wurzinger, 2016; Zewdie, 2017).

Table 10: Agrochemical utilization and distance of honeybee colonies from crop and pasture fields

Variables	Beekeepers (N = 270)		Non-beekeepers (N = 270)	
	n	%	n	%
Do you use agrochemicals to control crop pests, diseases, and weeds?				
Yes	264	97.8	270	100
No	6	2.2	-	-
Distance of colony placements from crop fields				
Less than 1 km	235	87	230	85.1
In the range of 1–5 km	30	11.1	32	11.9
Greater than 5 km	5	1.9	8	3
Do you use agrochemicals to control pasture land weeds?				
Yes	5	1.9	10	3.7
No	265	98.1	260	96.3
Distance of colony placements from pasture land				
Less than 1 km	254	94.1	248	91.9
In the range of 1–5 km	16	5.9	22	8.1
Greater than 5 km	-	-	-	-

n = number of respondents

Table 11: List of identified insecticides and fungicides used by farmers

Trade names	Active ingredient (AI)	Target pests /diseases	Crops where insecticides and fungicides applied
Profit 72% EC	Profenofos	Leaf hopper, onion thrip	Tomato, cabbage ,onion
Malathion 50%	Malathion	Aphid, armyworm, plusia	Tomato, cabbage ,onion, tef, millet, wheat, barley, grass pea , *chat* (*Catha edulis*), mango, avocado, orange
Gain 20 SL	Imidacloprid 20%	Aphid	Potato , tomato
Nimbecidine	Azadirachtin 0.03% EC	Thrip	Tomato, cabbage ,onion
Pritacet 10 EC	Acetamiprid 10%	Aphid	Cotton
Datrate 5% EC	Lambada-cyhalothrin 5% EC	Stalk borer	Maize, sorghum
Deltarin 25 EC	Deltamethrin 2.5%	African bollworm	Chickpea, grass pea
Agro-lambacine super 315 EC	Profenofos 30% + Lambda cyhalotrine 1.5%	African bollworm	Grass pea ,cotton
Ethiosulfan 35% EC	Endosulfan	Bollworm	Grass pea ,tomato, cabbage ,onion
Tricel 48% EC	Chloropyratose 48%	Termite	Pepper
Diazion60% EC	Diazion	Stock borer, cut worm, soil-born pests, armyworm	On all crop types including mango, avocado, orange
Ethiozinon 60% EC	Diazinon	Stock borer, cut worm,	On all crop types including

Trade names	Active ingredient (AI)	Target pests /diseases	Crops where insecticides and fungicides applied
		soil born pests, armyworm	mango, avocado, orange
Actellic 2% Dust	Pirimiphos-methyl	For the control of storage pests on cereals and pulses	Sorghum, maize, green mung, grass pea
Roger	Dimethoate 40% EC	For the control of horticultural pests	Cabbage , onion, mango, avocado, orange
Karate 5% EC	Lambda-cyhalothrin	For different pests	Cabbage , onion, green mung, grass pea, maize, tobacco
Phenetratite50%	Phenetratite50%	Aphid, armyworm, plusia	Tef, millet, wheat, barley
Daconil	Daconil	Coffee diseases	Tef ,millet, barley, coffee
Diazinon	Diazinon	Armyworm, plusia	Tef ,millet, barley
Megaban Plus	Chlorpyriphos-ethyl 48% w/v	Aphid, armyworm, plusia	Grass pea, cabbage , onion
Thionex 35 EC	Endosulfan	Thrip, ball worm	Grass pea , cabbage , Onion
Agrothoate40%	Dimethoate 40%	Aphid, armyworm, trip, ballworm	Millet, corn, sorghum, wheat, barley, onion, bean, pea, cabbage, potato, mango, avocado, orange
Diamog 40% EC	Dimethoate	Stalk borer, cut worm	Pulses, vegetables, potato
DDT	DDT	For various pests	Chat, mango, avocado, orange
Tilt 250 EC	Propiconazole	For the control of fungal diseases	Wheat, tomato, cabbage , onion , barley
Noble 25 WP	Triadimefon	For the control of stem rust and smut	Wheat, sugar cane
Bathion 640 ULV	Fenthion	For the control of *Quelea* bird	Sorghum, maize
Mancozeb 80%WP	Mancozeb	For the control of fungal diseases	Tomato, onion, pepper, chick pea, cabbage , lettuce, tobacco
Ridomil	Metalaxyl 40 g/kg + *Mancozeb* 640 g/kg	For the control fungal diseases	Tomato, onion, pepper, lettuce, cabbage
Natura	Propicnozole 250gm/l	For the control fungal diseases	Tomato, onion
Agro-laxyl MZ-63.5 WP	Metalaxyl 759/kg + Mancozeb 560gm/kg	Early and late blights, leaf spot	Tomato, potato

3.6.2. Herbicides used by farmers in the study area

The finding of the current study showed that different types of herbicides are used by beekeepers and non-beekeepers alike (Table 12). The majority of the farmers use different herbicides to control crop weeds. Livestock development agents and district livestock experts reported that farmers use herbicides on different cropping calendars. Farmers and development practitioners also stated that some level of conservation agriculture is practiced, in which Roundup is used. Previous studies also indicated for use of different types of herbicides by farmers to control crop weeds in the Amhara Region (Mengistu and Beyene, 2014; Begna, 2015; Sintayehu and Tibebe, 2016, Tassew and Wurzinger, 2016; Zewdie, 2017).

Table 12: List of herbicides in use by farmers in the study area

Trade names	Active ingredient (AI)	Nature of weeds	Types of crops	Stage of crop during application
Agro- 2,4-D Amine 720g/l A.E.	2,4-D 720 g/l A.E.	Crop weeds	Millet, corn, sorghum, wheat, tef, barley, rice	During flowering time, at the time of germination, and 30 to 35 days after seeding
Zura	2,4-D 720 g/l A.E.	Broad-leaved weeds	Millet, corn, sorghum, wheat, tef, barley	35–40 days after planting
Roundup	Glyphosphate 48%	Any weeds	Any crop	Before sowing
Glycel	Glyphosphate 48%	Broad-leaved weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence
Glymax	Glyphosphate 48%	Sedges, grasses, and broad-leaved weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence
Trustsate 360 SL	Glyphosphate 48%	Annual and perennial grasses and broad-leaved weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence
Linkosate 48 SL	Glyphosate-isopropyl ammonium	Annual and perennial weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence
Primagram	S-metolachlor 290 g/l + atrazine 370 g/l	Broad-leaved and grass weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence
Pallas 45 OD	Pyroxsulam	Grass and broad-leaved weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence
Butrazine 48 SC	Butachlor + Atrazine	Annual and perennial broad-leaved and grass weeds	Millet, corn, sorghum, wheat, tef, barley	Pre-emergence

3.6.3. Agrochemical mixing practices in the study area

Previous findings showed that mixing of different agrochemicals by smallholder farmers is a very common practice in different parts of Ethiopia (Tassew and Wurzinger, 2016; Mengistie *et al*., 2017; Zewdie, 2017). Likewise, in the present study during FGDs and KIIs, farmers and development practitioners described that mixing different types of agrochemicals is a common practice in the study area (Table 13). Instead of using a single type of agrochemical, farmers tend to mix two or three types of insecticides and also mix insecticides with fungicides. The reported reasons for mixing different types of agrochemicals were to save time and energy, create a synergistic effect, and minimize the cost of knapsack rental. Farmers do not, however, have any clear know-how on the ratio of the mixes. Farmers do not realize that this kind of mixing of products could even render agrochemicals less effective and cause adverse effects on their health, honeybees, and the environment. In this regard, Ngowi *et al*. (2007) reported that interactions among insecticides, fungicides, and minerals in water can influence the efficacy (making them more toxic, less efficient, neutralized, or resistant) of pesticides against fungal pathogens and insects, while some mixtures can induce phytotoxicity on tomato, onion, and cabbage. Overall, misuse of agrochemicals can expose farmers to acute and chronic health problems in the long run. Moreover, such practices may lead to pest and disease resistance to agrochemical applications.

Table 13: Mixing practice of agrochemicals in the study area

Agrochemicals combination	Types of agrochemicals
Endosulfan + Diazinon + Malathion	Three insecticides
Endosulfan + Diazinon	Two insecticides
Malathion + Diazinon	Two insecticides
Malathion + Mancozeb	Insecticide + fungicide
Mancozeb + Chlorothaloni	Two fungicides
Ridomil +Profit	Fungicide + insecticide
Mancozeb +Profit	Fungicide + insecticide
Glycel + 2, 4-D	Two herbicides
Roundup + 2, 4-D	Two herbicides

3.6.4. Agrochemical application time in the study area

As shown in Table 14, the majority of interviewed beekeeping respondents apply the agrochemicals on their crops in the morning (50%) and late afternoon (25.2%) periods when honeybee colonies are more active in foraging. Similarly, the majority of interviewed non-beekeeping respondents apply agrochemicals in the morning (58%) and at any time convenient (23%) for them. Thus, the results could explain how much the timing of agrochemical application is risky to honeybees. The results are in line with the findings of various scholars, who indicated that farmers apply agrochemicals at different times and overlap with the active honeybees-foraging period (Begna, 2015; Dawit *et al*., 2016; Sintayehu and Tibebe, 2016; Zewdie, 2017). The results also showed that all the respondents applied the different agrochemicals through the sprays.

Table 14: Time of agrochemicals application, mode of application, and their sources

Variables	Beekeepers (n = 270)		Non-beekeepers (n = 270)	
	n	%	n	%
Time of application				
Morning	135	50	157	58
Late afternoon	68	25.2	35	13
Night	21	7.8	16	6
Any time	46	17	62	23
Mode of application				
Dust	-	-	-	-
Spray	270	100	270	100
Source of agrochemicals				
Government	-	-	-	-
Traders	228	84.4	216	80
Cooperatives	42	15.6	54	20

n = number of respondents

3.6.5. Sources of agrochemicals in the study area

The major source of agrochemicals for both beekeepers and non-beekeepers is a trader (Table 14). Moreover, livestock development agents and district livestock experts pointed out that nowadays farmers purchase agrochemicals in the open market, shops, and veterinary pharmacies in very small amounts. Farmers also engage in retailing agrochemicals. Similar findings that farmers buy different types of agrochemicals from the local market in smaller quantities were reported by various authors (Begna, 2015; Mengistie *et al*., 2017; Zewdie, 2017). Other authors (Hiluf and Abebe, 2015; Fikre *et al*., 2016; Mengistie *et al*., 2017) similarly reported that farmers usually purchase the agrochemicals they need in the open market, from both licensed and unlicensed vendors. In addition, during the FGDs, farmers themselves reported that they usually buy agrochemicals in small quantities, either in the open market or from shops. They do not check the expiry date of the agrochemicals, as they lack knowledge on the importance of expiry dates and partly because they trust agrochemicals vendors.

It was also highlighted that the role of cooperatives in supplying agrochemicals is negligible, as cooperatives are inaccessible to most farmers. The cooperatives do not stock all the needed agrochemicals because they are not confident they will be able to sell enough if they hold a wide range of agrochemicals in large volumes.

3.6.6. Frequency of spraying and season of **agrochemical** *application in the study area*

About 29.6% of the beekeepers respondents apply agrochemicals only once, 27.4% twice, 31.9% three times, and 12.6% apply up to four times (Table 15). Similarly, 23.3% of the non-beekeeper respondents apply only once, 28.5% twice, 34.4% three times, and 13.7% apply up to four times. During the FGDs, both beekeepers and non-beekeepers stated that repeated spraying of agrochemicals on a single crop is very common. Livestock development agents also described that in most irrigated areas, such as Mecha and Fogera Districts, farmers spray insecticides up to 6–8 times on a single crop in a single cropping season. Moreover, district livestock experts and livestock development agents stated that farmers frequently used pesticides to control "chat" pests. A frequent spray of agrochemicals has also been reported by other authors (Begna, 2015; Mengistie *et al*., 2017; Zewdie, 2017).

The study also showed that different kinds of agrochemicals are used during the rainy and dry seasons (Table 16). Both beekeeper and non-beekeeper respondents follow a similar seasonal application of agrochemicals. The most common months of agrochemical application include June–September, November–December, and March–April.

Table 15: Frequency of agrochemical spraying

Frequency of spraying	Beekeepers (n = 270)		Non-beekeepers (n = 270)	
	n	%	n	%
Once	80	29.6	63	23.3
Twice	74	27.4	77	28.5
Three times	86	31.9	93	34.4
Four times	30	12.6	37	13.7

n = number of respondents

Table 16: Agrochemical application in relation to crop physiology

Crop stages	Months of application											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pre-sowing and pre-emergence (herbicides)												
Before flowering and at fruiting (insecticides, fungicides, herbicides)												
Whenever pests/diseases occur (insecticides, fungicides)												

3.6.7. Handling of agrochemicals in the study area

Both KII and FGDs discussants reported that the majority of farmers do not have access to skills training on how to handle and use agrochemicals. Farmers usually store agrochemicals anywhere in the house. Also, farmers and development practitioners reported that farmers throw empty agrochemical containers anywhere on the farm or around the residence (Figure 3). Similarly, Mengistie *et al*. (2017) findings showed that common ways of disposing of empty agrochemical containers include throwing them in the field and irrigation canals or rivers. Moreover, most of the disposal measures for agrochemical packaging come with significant environmental and health risks, as usually around 2%

of the agrochemicals still remain in the empty packaging (Briassoulis *et al*., 2014).

Farmers do not use protective clothes while spraying agrochemicals, as they do not feel protective clothes are important or have any idea about the importance of protective clothes. Farmers also reported that they do not get any advice from agrochemical dealers about how to use agrochemicals. This has been confirmed by livestock and beekeeping expert researchers and crop experts. Improper handling of agrochemicals and disposal of used containers has also been reported by several authors (Begna, 2015; Mengistie *et al*., 2017; Zewdie, 2017).

Figure 3: Handling of agrochemicals and containers in the study areas

3.7. Farmers' perception towards the impacts of agrochemicals on honeybees and honey

The results revealed that all the respondents confirmed that agrochemicals kill honeybees (Figure 4, Table 17). Similarly, all agricultural development practitioners, and livestock and beekeeping researchers also articulated that honeybees are at risk due to misuse and overuse of different types of agrochemicals. Especially, livestock and beekeeping development practitioners described the impact of agrochemicals on honeybees:

''Due to agrochemicals nowadays the death of honeybees is increasing from time to time in different parts of the region. '' They also explained that due to agrochemicals, the honeybees didn't return to the hive after their foraging trip. (FGD, February 2018)

Very surprisingly, only 2.7% of beekeeping respondents practice some level of protection of honeybees from the adverse effects of agrochemicals (Table 18). This condition will worsen the effects of agrochemical application on honeybee populations.

Table 17: Farmers' perceptions towards negative effects of agrochemicals on honeybees and honey quality

Variables	Beekeepers (n = 270)		Non-beekeepers (n = 270)	
	n	%	n	%
Do you think that agrochemicals have effects on honeybees?				
Yes	270	100	270	100
No	-	-	-	-
Did you practice any protection measure for honeybees from the negative effects of agrochemicals?				
Yes	10	2.7	-	-
No	260	96.3	270	100
Do you think that agrochemicals have effects on the quality of honey?				
Yes	24	8.9	-	-
No	246	91.1	270	100

n = number of respondents

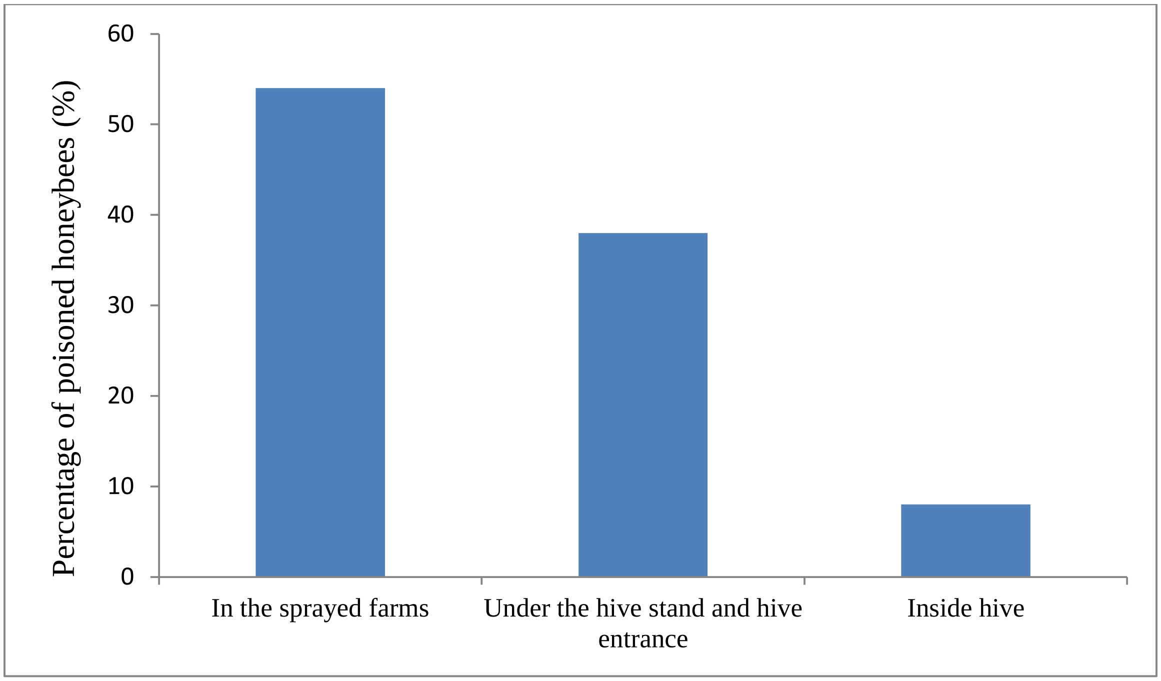

Figure 4: Locations where dead honeybees poisoned by agrochemicals were found

A significant colony loss due to agrochemicals has also been reported by several scholars in the region (Lowore, 2013; Begna, 2015; Zewdie, 2017). According to ARARI (unpublished report), the massive death of honeybee colonies in the Amhara Region is due to mis-and overuse of agrochemicals, and the highest massive colony death happens during the months of June to August and September to November. This period matches the flowering period of several crops and active honeybee foraging. The results also showed that the majority of the respondents do not know the negative effects of agrochemicals on the quality of honey.

3.8. Farmers' knowledge towards honeybee protection legal frameworks

The study revealed that all the respondents do not have information about the Apicultural Resources Development and Protection Proclamation (No. 660/2009) and Regulation (No. 372/2016) to protect honeybees from the negative effects of agrochemicals (Table 18). Furthermore, the results revealed that there was no bylaw used by the farming communities to protect honeybees from the negative effects of agrochemicals. But, in interviews, the farming communities see positively the importance of having a proclamation. On the other hand, livestock and beekeeping development practitioners and researchers emphasized the need for teaching both beekeepers and non-beekeepers about the importance of honeybees and the negative effects of agrochemicals on honeybees, the environment, and human health.

3.9. Farmers' knowledge towards the role of honeybees in crop pollination and integrated pest management practices

Regarding the crop pollination roles of the honeybees, 95.6% of the beekeepers and 97% of the non-beekeepers are not aware of the significant roles of honeybees in pollinating grain and horticultural crops (Table 19).

On the other hand, while integrated pest management (IPM) is a well-established method of pest control in the country and elsewhere globally, the majority of beekeepers (94.8%) and non-beekeepers (93%) do not know about IPM (Table 20). During the FGDs, beekeepers, non-beekeepers, and crop and livestock experts agreed that nowadays IPM is not being used by farmers as an option to reduce the use of synthetic agrochemicals. Livestock development practitioners expressed the use of agrochemicals in the farming communities as:

''The promotion of agrochemicals in relation to increasing crop productivity has however made a complete shift in the region. Moreover, nowadays most farmers do not see the importance of consulting extension workers prior to their decision to use agrochemicals for different purposes'' (FGD with regional livestock experts, April 2018).

Consequently, 97% of beekeeping and 95.2% of non-beekeeping respondents have never used or practiced IPM in their contexts. Previous findings also reported that the IPM option is not used by farmers (Begna, 2015; Zewdie, 2017). This suggests that strategies need to be designed to educate farmers on the importance of IPM and considering agrochemicals as a last resort.

Table 18: Knowledge of respondents on legal frameworks to protect honeybees against agrochemical effects

Variables	Beekeepers (n = 270)		Non-beekeepers (n = 270)	
	n	%	n	%
Do you have information about the Apicultural Resources Development and Protection Proclamation (No. 660/2009) and Regulation (No. 372/2016) to protect honeybees from the negative effects of agrochemicals?				
Yes	-	-	-	-
No	270	100	270	100
Do you have bylaws to protect honeybees from the negative effects of agrochemicals?				
Yes	-	-	-	-
No	270	100	270	100
Did you think such proclamations are needed?				
Yes	270	100	270	100
No	-	-	-	-

n = number of respondents

Table 19: Farmers' perceptions on the role of honeybees for pollination and use of IPM practices

Variables	Beekeepers (n = 270)		Non-beekeepers (n = 270)	
	n	%	n	%
Do you think that honeybees have a role in crop production?				
Yes	12	4.4	8	3
No	258	95.6	262	97
Do you know IPM?				
Yes	14	5.2	19	7
No	256	94.8	251	93
Have you ever practiced IPM?				
Yes	8	3	13	4.8
No	262	97	257	95.2

n = number of respondents

3.10. Economic losses of beekeeping due to agrochemical application

Data collected from beekeepers on the extent of honeybee colony death and absconding due to agrochemical application were used to estimate economic losses caused by the agrochemicals. Ethiopian Birr (ETB) 800 was taken as the average selling price of a single honeybee colony. The economic losses incurred are quite higher, more than ETB 5 million and ETB 6 million through colony death and absconding, respectively (Table 20).

Likewise, Begna (2015) estimated a financial loss of ETB5.46 million (or USD 273, 000) from beekeeping in the Mecha, Dangila, and Guangua Districts of the Amhara Region due to the application of agrochemicals. A financial loss of ETB 834, 910 has been reported in South Wollo and Waghimra Zones (Alemu, 2015) and ETB226, 548 in the Chilga District of Amhara Region (Zewdie, 2017).

Table 20: Estimated economic losses of agrochemicals from losses of honeybee colony

Type of loss of honeybee colonies	Number of honeybee colonies	Total economic losses*
Death	6,300	ETB5,040, 000.00 (USD184, 683.00)
Absconding	8,100	ETB6,480,000.00 (USD237, 450.00)
Total	14,400	ETB11,520,000.00 (USD422,133.00)

*One honeybee colony is estimated to cost ETB 800.00 or USD 29.30

3.11. Implications for sustainable beekeeping, crop and livestock production

Nowadays, there is high interest and investment in transforming Ethiopia's beekeeping sub-sector. However, the health of honeybees is at risk due to indiscriminate use of agrochemicals both by beekeepers and non-beekeepers. The observed mass death of honeybees would have detrimental effects on the livelihoods of smallholder farmers in the Amhara Region. The mass death of honeybees will have a substantial negative impact on the production and quality of bee products. Furthermore, among the major crops grown in the Amhara region that require pollination services are peas, beans, soya beans, tomatoes, avocado, mango, coffee, papaya, and watermelon. This means that without honeybees, grain, vegetable, and fruit harvests would suffer greatly due to a lack of pollination services given by honeybees. This is also a global phenomenon and hence the decline in honeybee populations poses significant threats to food production in many parts of the world (Potts *et al.*, 2010; Bianco *et al*., 2014). Many grains and horticultural crops are dependent on pollination services of honeybees (Bradbear, 2009). Similarly, major forage plants for livestock production, such as alfalfa and clover, rely on honeybees for pollination, and the mass death of honeybees will have an impact on seed output from those forage plants.

4. Conclusion and Recommendation

Mixed farming system is a common practice for the majority of farmers in the study areas and in the Amhara Region in general which combines crop, and livestock production including beekeeping to diversify their livelihoods and reduce farming risks. Nonetheless, the indiscriminate application of agrochemicals both by beekeepers and non-beekeepers alike, in crop production to control insect pests, diseases, and weeds, and in some cases pasture land weeds, were indeed found to be the major factors responsible for the mass killing of the honeybees in Amhara Region. Beekeepers, non-beekeepers and both crop and livestock experts revealed that nowadays integrated pest management has not been used by farmers as an alternative to synthetic agrochemicals. Farmers are also unaware of the legal frameworks available to protect honeybees from the negative effects of agrochemicals, and they have not developed local bylaws that can be used by farming communities to protect honeybees from the negative effects of agrochemicals. The results also showed that the direct economic losses incurred due to loss of honey bee colonies from the indiscriminate application of agrochemicals run into ETB11,520,000.00 /USD422,133.00/. As a matter of fact, both enterprises being equally important it is not possible to intensify crop production at the expense of the livestock sector, especially beekeeping or vice versa suggesting that a win-win solution is needed.

Therefore, concerned and responsible stakeholders must take action to mitigate the unintended consequences of agrochemicals on beekeeping, including training and awareness creation for farmers on the negative effects of agrochemicals and best practices to minimize the negative effects of agrochemicals on honeybees, the role of honeybees in pollinating vegetables, fruits, cereal crops, and forages, thereby contributing to crop productivity, and awareness creation for policy and decision makers to enforce legal frameworks on agrochemicals use. The interventions should be carried out in a system-wide, context-specific, and integrated approach.

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Data availability statement

Data will be made available on request.

Conflicts of interest

The authors declared that there is no conflict of interest.

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