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EFFECTS OF HERBICIDE APPLICATION IN WHEAT CROPS AND ON HONEYBEE POPULATIONS IN ETHIOPIA

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Cover image: herbicide spraying practice in Oromia region
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Research Report
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ACRONYMS AND ABBREVIATIONS

AGP	Agricultural Growth Program
a.i.	active ingredients
AMDe	Agribusiness and Market Development
ATVET	Agricultural Technical Vocational Education and Training
DA	Development Agent
FGD	Focus Group Discussion
F/PTC	Pastoralist/Farmers Training Center
FTC	Farmers Training Center
GDP	Gross Domestic Product
ha	hectare
HH	Household
IPM	Integrated Pest Management
IWMSS	Integrated Weed Management Support System
kg	Kilogram
KII	Key Informant Interview
MoA	Ministry of Agriculture
NGO	Non-governmental Organization
SMS	Subject Matter Specialist
SPSS	Statistical Package for the Social Sciences
UNEP	United Nations Environment Program
USAID	United States Agency for International Development

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EXECUTIVE SUMMARY

After South Africa, Ethiopia is the second-largest wheat producer in sub-Saharan Africa. Over 4.7 million households are involved in wheat production annually, producing about 3.9 million tons of wheat across 1.6 million hectares of land, with average productivity of 2.4 t/ha. However, national wheat production does not meet the country's demand. The annual estimated deficit of 25–30% is met by imported grain. Wheat is among the most important crops in Ethiopia, ranking fourth in total cereals production after maize, sorghum, and teff. It is grown as a staple food in the highlands at altitudes ranging from 1,500 to 3,000 meters above sea level. Nearly all wheat in the country is produced under rain-fed conditions, predominantly by small farmers. Production volumes have been increasing due to the implementation of improved packages in which herbicide is one component.

Herbicide use has become widespread, along with an agricultural intensification program and the need for increased food production for food security. Farmers in Ethiopia often cannot cope with heavy weed infestation during the peak period of agricultural activities because of a labor shortage. Most fields are weeded late or left un-weeded, resulting in remarkably reduced production. Hence, herbicidal weed management is indispensable, especially when there is a labor shortage. The herbicides 2,4-D, Roundup/Glyphosate, Topic, and Palace are commonly used, separately or in combination. It is not uncommon to find peasant farmers in rural Ethiopia using or overusing these herbicides without fully understanding the undesirable consequences on bees and other crop pollinators, on bee forages, and on other non-target organisms, and on the environment at large.

Ethiopia is endowed with enormous and untapped apicultural resources. Long-standing traditional beekeeping practices are well established in almost all parts of the country and contribute to household food security and livelihood by providing income, quality food, and assets to beekeepers. With about seven million honeybee populations, the country ranks as the ninth-highest honey producer in the world and the leading producer of honey and beeswax in Africa. The country's annual honey and beeswax production is estimated to be over 54,000 tons and 5,000 tons, respectively. However, the share of this sub-sector in the GDP has never been commensurate with the huge numbers of honeybee colonies. Production and productivity have been low, leading to low utilization of hive products domestically, and relatively low export earnings. Among the most limiting factors is the ever-increasing grievance of pesticide effect on bee colonies. Product decline has considerable economic impacts on smallholder beekeepers. The decline is due to a common package practice of increasing wheat production and productivity without due attention to the huge apiculture potential in many regions.

In view of the above, this research was initiated with the objective of assessing the effects of herbicide application in wheat crops and on honeybee populations in three major beekeeping districts of Endamekhoni (southern Tigray Zone, Tigray Region), Dangila (Awi Zone, Amhara Region), and Agarfa (Bale Zone, Oromia Region). A mix of both quantitative and qualitative methods of assessment was employed. Formative data were collected from beekeepers and DAs using structured questionnaires, and in-depth interviews were conducted with key informants. Discussion with focus groups for qualitative information was conducted and analyzed. In summary, the analysis of data revealed that the majority of beekeepers in Endamekhoni have abandoned the use of herbicides in their wheat fields over the past five years or so and instead practice hand-weeding using family labor. They obtain a better yield and quality of honey. On the other hand, farmers in Dangila and Agarfa districts continuously use herbicides in their wheat fields, with consequential loss in the populations of bee colonies and in the amount of honey harvest and its quality, damage to bee forages, and toxicity to crop and pollinators and the environment at large. Hence, there is a need for an integrated and sustainable crop-apiculture development strategy based on bio-intensive IPM and ecological principles and practices in the three regions. This strategy should be implemented through a system approach to fight system bottlenecks of high levels of illiteracy, inadequate enforcement of policies and legal standards, inadequate safety precautions and safety devices, improper herbicide labelling, and insufficient knowledge base in general.

1 INTRODUCTION

1.1 Background and Significance of the Study

Ethiopia is the largest wheat producer in sub-Saharan Africa. In Ethiopia, wheat is the most important cereal crop in terms of the area of land allocated, volume produced, and the number of farmers engaged in its production. About 4.7 million farmer households are involved in the production of about 3.9 million tons of wheat across 1.6 million hectares of land, with an average productivity of 2.4 t/ha.

Although efforts are being made by the government and other development partners, such as USAID, the wheat supply does not meet the national demand; the estimated annual deficit is about 25–30%, which is filled by imported grain from other countries (USAID, 2014). One of the most limiting factors in the production of wheat in Ethiopia is grass and broad-leaved weeds.

To control the weeds in a wheat field, herbicides are heavily used in the study regions, which in turn affect bees and other organisms and the environment. In Ethiopia, beekeeping is a traditional agricultural practice in the mixed farming system of the country. The presence of adequate water resources and various honeybee floras creates a conducive environment for the practice of beekeeping. Because of the ideal climatic conditions and diverse floral resources, Ethiopia has the highest bee density in Africa (Kassaye, 2001; Nuru, 2002). Beekeeping is a common practice in most regions of the country. Oromia, Amhara, and Tigray Regions are representative regions where beekeeping is widely practiced.

In addition to having the highest bee density in Africa, Ethiopia is also the leading honey producer and the largest beeswax exporter in Africa. Despite this long tradition of beekeeping, the share of the subsector in the GDP has never been commensurate with the huge numbers of honeybee colonies and the country's potential for beekeeping. Productivity has always been low, leading to low utilization of hive products domestically and relatively low export earnings. The beekeepers in particular and the country in general are not benefiting from the subsector (Nuru, 2002). Several studies have indicated that the number of honeybee colonies has been declining, and consequently honey and beeswax production and export earnings have been declining (Tadesse, 2001). This was largely attributed to indiscriminate application of herbicides and other pesticides, drought, ever-increasing population pressure, and associated vegetation changes.

Agricultural intensification and loss of habitat are the major causes of impoverished pollinators and consequent reduced honey yield. The problem is even more dangerous when it comes to the use of genetically modified crops to resist pest attack, which has a double effect on pollinators because modification of crops to resist broad-spectrum herbicides that can destroy weeds effectively might remove the habitat and foods of bees and other pollinators from the area (Richards, 2001), thus damaging important bee forages and affecting wild and managed honeybees. For instance, chemical destruction of habitats through massive application of herbicides could have long-term consequences, particularly on the distribution and abundance of pollinators in agroenvironments (UNEP, 2010). Effects of herbicides on the honey production system have not been examined in the country, and there is a need to explore its effects so as to improve honey production in a sustainable manner. Therefore, this study investigates the effects of herbicides in wheat crops and on honeybee populations and proposes a risk reduction intervention strategy and legal framework that would protect honeybee colonies and associated resources and the agroecology from herbicide poisoning and thereby maximize returns both from crops and apiculture in a "fair" and balanced manner.

1.2. Statement of the Problem and Key Research Questions

Though Ethiopia has diverse and unique flowering plants suitable for beekeeping, the bees and the plants, like all renewable natural resources, are constantly under threat due to haphazard and irrational use of agrochemicals for crop production. Among other pesticides, herbicide poisoning of bees is one of the major constraints that affects apiculture industry in Ethiopia (Kinati et al., 2013). Although herbicides have a great role as part of a package of technology for yield improvement in different crops, they have their own undesirable side effects on environmental and public health resulting from lack of awareness and improper management skills and disposal facilities (Ecobichon, 2001). At a global level, the amount of pesticides used in 2000 and 2001 was approximately 2.5 million tons a.i. (Anonymous 2007a), and herbicides accounted for the largest portion of total use, about 35% in 2000 (Anonymous 2007b). Herbicides are most extensively used in developing countries, including Ethiopia, causing heavy loss of bee colonies and other environmental hazards.

Inappropriate use of herbicides has great negative impact on beekeeping activity and on other natural resources. Such impacts include death of bees, honey production loss, contamination of bee products, and reduction in the yield of cross-pollinated crops. Both harmful and beneficial organisms are killed, and substances released from chemical reactions contaminate the environment, leading to climate change, pest resistance, and biodegradation (Ajayi, 2005). These harmful effects can be due to direct exposure of honeybees to herbicides/pesticides or through indirect contact with their residues as reported by beekeepers.

About 541,467 liters of pesticides are aerially sprayed on 514,923.6 hectares to control crop pests in the regions of Ethiopia with the highest beekeeping potential, namely Oromia, Amhara, and Tigray, of which Oromia and Amhara Regions comprise the largest proportion. Very limited research has been done to explore the effects of herbicide on honeybee populations and honey productivity trends in wheat crop-producing region of the country. Therefore, this research project is initiated to address the following key research questions: What are the effects of herbicide application in wheat crops and on honeybee populations? What are the effects of herbicides on honeybees? How does herbicide affect honey productivity in the study regions? What are the yield trends of honey in the study areas of the country? How does the use of herbicide in wheat crops constrain the beekeeping activities of farmers in the study regions? What is the herbicide-related knowledge and perception of beekeepers and DAs in the study regions? The answers to the above questions might help farmers/beekeepers to seek a proper herbicide management support system, which should be available through the DA-facilitated extension service delivery system of the country.

2 RESEARCH OBJECTIVES

2.1. General Objective

The general objective of this research project is to determine the effects of herbicide application in wheat crops and on honeybee populations in Oromia, Amhara, and Tigray Regions.

2.2. Specific Objectives

The specific objectives of the study include:

- To assess the effects of herbicides application on bee populations in the selected districts of Oromia, Amhara, and Tigray Regions
- To assess the effects of herbicide application on bee forages
- To assess herbicide impact on the honey harvest
- To assess herbicide-related knowledge and perception of beekeepers/farmers and service delivery by DAs
- To propose intervention mechanisms for mitigating prevailing problems.

2.3. Literature Review

2.3.1. Importance of beekeeping

Beekeeping is a non-farm business activity that has immense contributions to the economy of the society as well as to the national economy as a whole. For maximization of honey production and efficient utilization of resources, migratory beekeeping can be exercised in areas where honey forages provide rich honey flowers in succession (Kerealem and Nuru, 2005). Beekeeping has many advantages that help farmer beekeepers to improve their well-being. Its advantages can be itemized for the socioeconomic impact of beekeeping. For instance, successful beekeepers raise their socioeconomic standing in areas with subsistence agriculture, and farmers in developing countries can substantially supplement the family income, sometimes even double it. This means that smallholder farmers can be food secure through the improvement of their beekeeping practices.

2.3.2. Effects of herbicides on honeybees

Honeybees and wild bees play a significant role in pollinating wheat and other crop plants globally. Their contribution to global agriculture amounts to several billion dollars every year (Pimentel, 1996). However, agricultural intensification and loss of habitat are causing impoverishment of pollinators, resulting in reduced crop yield. The problem is even more dangerous when it comes to the use of genetically modified crops to resist insect attack, which has a double effect on pollinator insects because modification of crops to resist broad-spectrum herbicides that can destroy weeds effectively might remove the habitat and foods of honeybees and other pollinators from the area (Richards, 2001).

There seems to be general agreement that declines in bee populations and in their overall health are the product of multiple factors, both known and unknown, which can act singly or in combination (Williams et al., 2010; Potts et al., 2010). Among the key factors known or thought to be causing bee declines is the use of herbicides on crop fields that wipe out wild flowers on which bees feed (Allsopp et al., 2014). Large-scale herbicide application in and around cultivated farm fields drastically reduces the diversity and abundance of weeds and wild flowers. This limits pollen and nectar, and thus food availability, for bees (Allsopp et al., 2014). Manipulation of habitats through massive application of herbicides can have long-term consequences, particularly on the distribution of crop pollinators in agroecosystems (UNEP, 2010).

In general, the use of herbicides in developing countries, including Ethiopia, is small when compared to developed countries. However, the negative effect is high in the three regional states of Ethiopia due to high levels of illiteracy, inadequate enforcement of herbicide policies, regulations, and guidelines, inadequate safety precautions and safety devices, improper herbicide labelling and quality control, and insufficient knowledge in handling and proper use of herbicides by farmers and beekeepers. This scenario demands policy consideration and strategic intervention for improvement.

3 STUDY SITE, APPROACH, AND DATA COLLECTION METHODOLOGY

3.1. Locations of the Study Areas

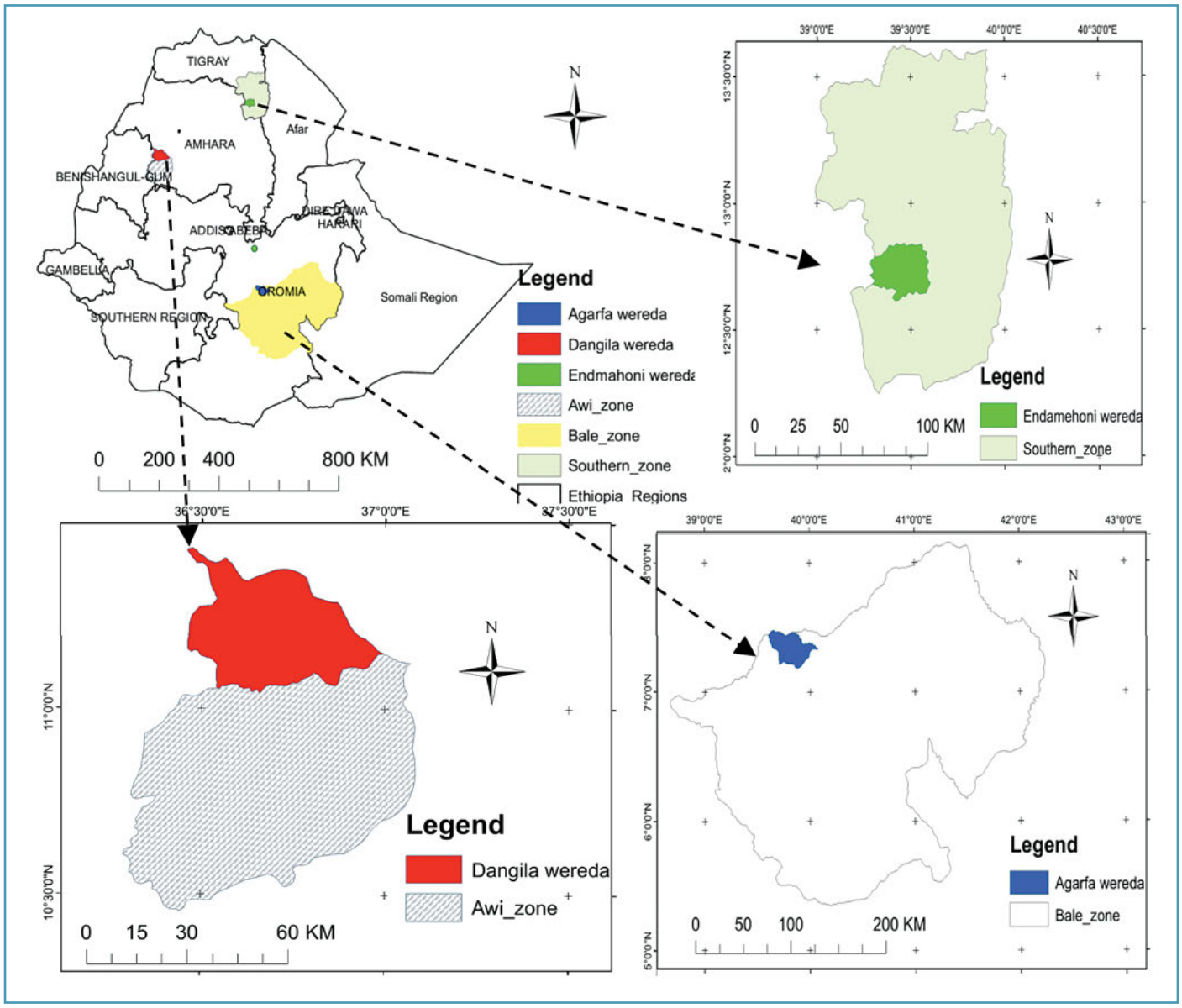

Figure 1. Location map of the study areas.

3.2. Approach and Data Collection Methodology

This study was conducted in three potential beekeeping *woredas*, namely, Agarfa, Dangila, and Endamekhoni, of Oromia, Amhara, and Tigray Regions, where wheat is dominantly cultivated. A combination of both qualitative and quantitative data collection techniques was employed in order to achieve the study objectives. Both primary and secondary sources of data were used. The primary data collection methods involved a quantitative field survey with smallholder beekeepers using semi-structured questionnaires. Qualitative data were obtained using key informant interviews (KIIs) with regional bureaus, zonal departments, *woreda* and *kebele* agricultural extension officers, subject matter specialists (SMSs), DAs, and *kebele* agriculture office representatives. Focus group discussions (FGDs) were held with male and female farmers (in 50% of the *kebeles*) and youth and adult smallholder farmers. Other published and unpublished materials were used in the collection of qualitative data. Secondary data were obtained from reports of *Kebele* Agriculture Office representatives, *Woreda* Agricultural Development Offices,

Zonal Agricultural Departments, Regional Bureaus of Agriculture and Natural Resources Departments, NGOs, and Farmers Unions and Cooperatives.

3.2.1. Data collection methodology

The specific methodologies employed were a mix of quantitative and qualitative data collection techniques, presented below. A purposive random sampling technique was employed to select the sub-districts or *kebeles* out of the total *kebeles* of each *woreda* in the selected regions. Selection of *kebeles* within sample *woredas* took into account different agroecological zones. Before selecting samples, *kebeles* within each sample *woreda* were categorized into three different agroecological zones or strata (Kolla, Weina Dega, and Dega). Sample *kebeles* were chosen from each of the strata. Development teams, locally called "*limat-budens*" in the sub-localities named as "*gotts*" from each sample *kebele*, were taken using simple random sampling techniques. Sample beekeepers from each *kebele* were therefore selected using a systematic selection scheme. *Gotts/limat budens* were considered, since *kebeles* under the current structure were too big to be taken. A checklist of *gotts/limat-budens* was obtained from each *kebele*. Thus, twenty-five beekeepers/households and available female-headed households/beekeepers were purposively selected from each *kebele* in each study region. A total of 800 households in the three *woredas* of the three regions were selected.

3.2.2. Data sources and nature of data to be collected

The study required a wide range of information with reference to effects of herbicides in wheat crops and on bee and beekeeping practices. As stated above, both qualitative and quantitative data were generated, along with information on the general background of the household characteristics and farms, herbicide use, herbicide knowledge, and perception of smallholder beekeepers and DAs about herbicide effects in the wheat crop and on bees, bee forages, and honey yield in different seasons. The questionnaire was first developed in English and later was translated into local languages (Oromifa, Amharic, and Tigrigna) for field use and was translated back into English before data entry and analysis. The survey method of Arsham (2005) was employed to collect data on various aspects of the subject under discussion.

3.2.3. Data management, processing, analysis, and reporting

Data were edited, coded, entered, and tabulated for analysis, and data analysis was conducted with SPSS new software (version 20) for Windows. Frequency distribution and percentages were used to describe and report the findings according to each specific objective. Based on the lessons learned and the conclusions drawn from the findings, the research team drew lessons from the findings and formulated a cohesive set of strategic conclusions and recommendations that can be pursued for mitigating herbicide management challenges and of constraints for sustainable apiculture development, biological conservation, and environmental management in the study area.

4 RESULTS AND DISCUSSION

The current study assessed the general background of the interviewed beekeepers' household characteristics and farms, herbicide effects in wheat crops and on bees, and yield trends of honey, herbicide use, bee forages, and herbicide knowledge and perceptions of beekeepers in Tigray, Amhara, and Oromia Regions. The study also assessed the gender equality of DAs, their level of education within their specialization, their opportunities to get training in beekeeping, and their knowledge and perception of herbicide effects on bees within the framework of the current scenarios of the FTCs and with due consideration of the enabling environment within which the agricultural extension system operates.

This report presents the results of effects of herbicide application in wheat crops and on honeybee populations in the three regions of Ethiopia along with the extension service delivery by DAs on beekeeping technology and herbicide use and management and its effect on bee colonies.

4.1. Background of Beekeepers' Household Respondents

4.1.1. Household characteristics

Of the total 800 sample respondents, 82.5% were males. The largest number of male beekeepers were found in Oromia (91.2%), followed by Amhara (84%) and Tigray (70.7%) (see Table 1), while the largest number of female beekeepers were recorded in Tigray Region (29.3%) from the total of 225 sample respondents in that region. This agrees with the traditional idea that beekeeping is a man's job, due to the physical capacities that men claim to have. Actually, this belief might not hold true if women were given equal opportunities in heading the family as their male counterparts and were provided with beehive handling and management on their own in the proximity of their backyards or homesteads. Most of the sample beekeepers (80.0%) were married, while 0.9% and 19.1% were single and other (divorced or widowed), respectively.

Individuals in the age group category of between 15 and 65 years are considered economically active in many findings. In this study, this age category is the largest (95.6% out of 225 beekeepers) in Tigray, followed by Amhara (95.4% out of 325 beekeepers), and Oromia (93.6% out of 250 beekeepers). Generally, 94.9% of the total interviewed beekeepers in this study belong to the age category of between 15 and 65 years of age, indicating that people both young and old were actively engaged in beekeeping activities. The family size of most of the sample beekeepers of the study *woredas* varied between five and ten individuals, with 80.3% (Amhara), 73.8% (Tigray), and 70.8% (Oromia) in that category. This indicates the enormous labor input potential for beekeeping practices and other agricultural activities in the three regions.

Table 1. Selected* kebeles, *households (HHs), and distribution of DAs, by region

No.	Region	Zones	*Woreda*	*Kebeles*	HHs	DAs
1	Tigray	South-ern Zone	Endamekhoni	1. Nikah	17(F8)	(F3)
				2. Senay	18(F7)	(F1)
				3. Hadinet	18(F7)	(F2)
				4. Simret	17(F8)	2
				5. Mehan	17(F8)	(F1)
				6. Meswaeti	19(F6)	1(F1)
				7. T/haya	17(F8)	(F1)
				8. Hiziba	18(F7)	1(F1)
				9. Embahasty	18(F7)	1(F2)
			Sub-total		225	17
2	Amhara	Awi Zone	Dangila	1. Affessa	21(F4)	2
				2. Jibana	25	1
				3. Alefa qacha	19(F6)	1(F2)
				4. M/zelessa	25	(F1)

				5. Wubri	20(F5)	2
				6. Washa	25	2
				7. G/sahara	20(F5)	2
				8. Gumdri	21(F4)	1
				9. Dengeshita	19(F6)	1
				10. G/kanssen	21(F4)	1(F1)
				11. Wondefay	18(F7)	1(F1)
				12. Abadira	19(F6)	1
				13. Gult	20(5)	(F1)
			Sub-total	325	21	
3	Oromia	Bale Zone	Agarfa	1. Ambentu	22(F3)	1
				2. Amalema	25	1
				3. O/negelle	19(F6)	1
				4. Mekona ferejo	25	1
				5. Galama hebeno	25	1(F1)
				6. Kasomanso	25	1
				7. Mekona cheffe	23(F2)	(F1)
				8. Kasowarra	25	(F2)
				9. Ali	19(F6)	1(F1)
				10. Elebido	20(F5)	(F1)
			Sub-total		250	13
Total				32	800	51

Key: F = Female, (Fn) = Number of females; 17.5% female and 82.5% male HHs; 47.05% female and 52.95% male DAs

4.1.2. Farm size of sample respondents

As a result of the high population and the mountainous topographical nature of most regions, a shortage of productive land in particular and arable land in general characterizes the prevailing farming system. Among the three, in Oromia Region the highest percentage (54.4%) of the respondents has a farm size of above two but less than five hectares, while the lowest percentage (1.2%) of the respondents has a farm size of less than or equal to 0.25 hectares. In Amhara Region, the highest (34.5%) percentage of the respondents has a farm of above 0.25 but less than one hectare, while 4.0% of the interviewed beekeepers has a farm of less than or equal to 0.25 hectares. In Tigray Region, the highest percentage (61.3%) of the interviewed beekeepers has a farm size of above 0.25 but less than one hectare, while the rest of the beekeeper respondents has a farm size of less than one and 1.5 hectares. This is in line with the general fact that beekeeping can be exercised with a minimal land holding where land is a limiting factor (Table 2).

Table 2. Farm size of respondents, by region

Farm size	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Less than or equal to 0.25 ha	77	34.2	13	4.0	3	1.2	93	11.6
Greater than 0.25 ha but less than 1 ha	138	61.3	112	34.5	40	16.0	290	36.2
Greater than 1 ha but less than 1.5 ha	9	4.0	65	20.0	21	8.4	95	11.9
Greater than 1.5 ha but less than 2 ha	1	0.4	50	15.4	44	17.6	95	11.9
Greater than 2 ha but less than 5 ha	0	0.0	85	26.2	136	54.4	221	27.6
Above 5 ha	0	0.0	0	0.0	6	2.4	6	0.8
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

4.1.3. Educational status of sample respondents

Education is an important entry point for empowerment of rural communities and an instrument to sustain development. The government emphasis under this activity in beekeeping and management is to ensure that community members (children and adults) get basic educational services and have as many literate community members as possible who can strive to solve their problems by themselves.

The educational level of the farming households may have significant importance in identifying and determining the type of development and extension service approaches. Education plays an important role and affects household income, the adoption of technologies, demography, health, and as a whole, the socioeconomic status of the family and the community at large (Kerealem and Nuru, 2005).

An assessment of the educational status of respondents in Tigray Region indicated that about 46.7% of them did not receive any education, while 53.3% were literate with their level of education ranging from basic to diploma and above. In Amhara and Oromia Regions, 39.1% and 16% of the interviewed beekeeper were non-educated, while the rest (60.9% and 84%, respectively) were educated, with levels ranging between ability to read and write to diploma and above (see Table 3).

Table 3. Respondents' educational status, by region

Educational status	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N%	n	N %	n	N %	n	N %
No education	105	46.7	127	39.1	40	16.0	272	34.0
Basic education	4	1.8	99	30.5	64	25.6	167	20.9
Elementary	97	43.1	89	27.4	119	47.6	305	38.1
High school	17	7.6	9	2.8	22	8.8	48	6.0
Diploma and above	2	0.9	1	0.3	5	2.0	8	1.0
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

4.2. Herbicide Use-practice by Beekeepers

4.2.1. Herbicide preference by beekeepers in the three regions

Results of analysis of data on herbicide preferences of farmers in the three *woredas* of the three regions (Table 4) reveals that there is zero preference for herbicides in the Endamekhoni *woreda* of southern Tigray where the use of herbicides on wheat fields has largely been abandoned by the majority (93.8%) of farmers for over five years, with the objective of safeguarding their bee colonies from herbicide poisoning and death. This has been brought to the attention of the *woreda* office of agriculture and *woreda* cabinet, which approved farmers' decision on non-herbicide production of wheat. Farmers convinced the *woreda* cabinet that they can manage weed management through hand-weeding by family labor or groups since they are smallholders with a farm size not exceeding 0.5 ha per household. They further added that the use of an external input such as herbicides is not economical in view of the availability of cheap family labor and the scarcity of productive land. On the other hand, farmers in Amhara and Oromia Regions use a variety of different herbicides against weeds in their crop fields. As depicted in Table 4, 67.7% of respondents in Amhara Region use 2,4-D and Roundup, while 70.4% of such respondents in Oromia Region prefer to use 2,4-D and Palace, depending on the type of crop, cost of herbicides, and other related factors.

4.2.2. Herbicide application on a monthly basis

Efforts were also made to look at the time of application of herbicides by respondents in the three *woredas* of the three regions. Analysis of results indicates that 70.8% of the farmers in Oromia use herbicides in the month of September, whereas 39.3% and 28% of respondents in Amhara Region use herbicides in the months of July and August, respectively, while the majority (93.3%) of respondents do not use herbicides on any of their crops in any month in Endamekhoni *woreda* of southern Tigray (see Table 5).

Table 4. Herbicide preference of respondents, by region

Type of herbicide	Number and % respondents							
	Tigray		Amhara		Oromia		Total	
	n	N %	n	N %	n	N %	n	N %
2,4-D	14	6.2	18	5.5	0	0.0	32	4.0
Palace	0	0.0	0	0.0	29	11.6	29	3.6
Topic	0	0.0	0	0.0	13	5.2	13	1.6
2,4-D and Roundup	0	0.0	220	67.7	0	0.0	220	27.5
2,4-D, Palace, and Topic	0	0.0	0	0.0	3	1.2	3	0.4
Roundup	0	0.0	6	1.8	29	11.6	35	4.4
2,4-D and Palace	0	0.0	0	0.0	176	70.4	176	22.0
Other	0	0.0	0	0.0	0	0.0	0	0.0
None	211	93.8	81	24.9	0	0.0	292	36.5
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

Table 5. Monthly usage of herbicide application, by region

Month herbicide sprayed	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
May	0	0.0	6	1.8	3	1.2	9	1.1
June	0	0.0	22	6.8	3	1.2	25	3.1
July	3	1.3	127	39.1	12	4.8	142	17.8
August	10	4.4	91	28.0	55	22.0	156	19.5
September	1	0.4	0	0.0	177	70.8	178	22.2
None	211	93.8	79	24.3	0	0.0	290	36.2
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

4.2.3. Herbicide use by wheat growers

Regarding herbicide application, 99.2% of respondents in Oromia reported that they use herbicides regularly, while 37.8% of respondents in Amhara Region use herbicides occasionally, as shown in Table 6 below.

4.2.4. Frequency of herbicide application

As shown in Table 7, response regarding spray frequency of herbicides by sample farmers indicated that 52.8% of farmers apply herbicides once per year and 45.6% of them twice per year in Oromia. Similarly, 49.5% of respondents in Amhara Region apply herbicides once per year.

4.2.5. Use of herbicide guidelines

Table 8 below shows that 46% and 63.1% of farmers sometimes follow guidelines on the use of herbicides in Oromia and Amhara Regions, respectively. However, 94.2% of respondents in Tigray reported that this does not apply to them.

Table 6. Respondents on application of herbicides, by region

Herbicide use	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Regularly	4	1.8	119	36.6	248	99.2	371	46.4
Occasionally	10	4.4	123	37.8	2	0.8	135	16.9
None	211	93.8	83	25.5	0	0.0	294	36.8
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

Table 7. Annual spray frequency of herbicide, by region

Annual herbicide spray frequency	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Once	11	4.9	161	49.5	132	52.8	304	38.0
Twice	3	1.3	72	22.2	114	45.6	189	23.6
Three times	0	0.0	8	2.5	4	1.6	12	1.5
More than three times	0	0.0	2	0.6	0	0.0	2	0.2
None	211	93.8	82	25.2	0	0.0	293	36.6
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

Table 8. Use of herbicide use guidelines, by region

Guideline usage for herbicide application	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Yes, always	3	1.3	9	2.8	78	31.2	90	11.2
Yes, sometimes	10	4.4	205	63.1	115	46.0	330	41.2
No	212	94.2	111	34.2	57	22.8	380	47.5
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

4.3. Herbicide Knowledge and Perceptions of Beekeepers in the Three Regions

4.3.1. Knowledge of beekeepers of herbicide effects

Efforts were made to assess the knowledge base of farmers on the side effects of herbicides. Results of analysis of data indicated that 96.9% (Tigray), 97.8% (Amhara), and 95.6% (Oromia) of interviewed farmers responded that they well understand and recognize the undesirable effects of herbicides on the livelihoods of their bees (see Table 9).

4.3.2. Knowledge and perception of beekeepers about herbicides in the three regions

Results of the assessment of the nature of perception of beekeepers about herbicides (see Table 10) indicated that 37.8% and 39.6% of the respondents in Tigray stated that herbicides are sometimes harmful and always harmful, respectively, whereas 76.0 % of those in Amhara Region responded that they do not know. In Oromia, however, 48.8% of respondents reacted by stating that herbicides are sometimes harmful.

4.3.3. Personal protection during applications of herbicide

The figure below (Figure 2) depicts the response of farmers on personal protection requirements during herbicide application. In Tigray, 58.2% of the respondents do not care about personal care during herbicide application since they do not use herbicides, whereas 44.6% in Amhara care about personal protective requirements, and 74.4% responded "yes" in Oromia Region.

Table 9. Knowledge of the effects of herbicide, by region

Knowledge of side effects of herbicide	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Yes, I know	218	96.9	318	97.8	239	95.6	775	96.9
No, I don't	7	3.1	7	2.2	11	4.4	25	3.1
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

Table 10. Level of perception of beekeepers about herbicides, by region

Perception of beekeeper towards herbicide	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Always good	1	0.4	1	0.3	11	4.4	13	1.6
Sometimes good	32	14.2	28	8.6	43	17.2	103	12.9
Sometimes harmful	85	37.8	49	15.1	122	48.8	256	32.0
Always harmful	89	39.6	0	0.0	16	6.4	105	13.1
Useless	1	0.4	0	0.0	0	0.0	1	0.1
I don't know	17	7.6	247	76.0	58	23.2	322	40.2
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

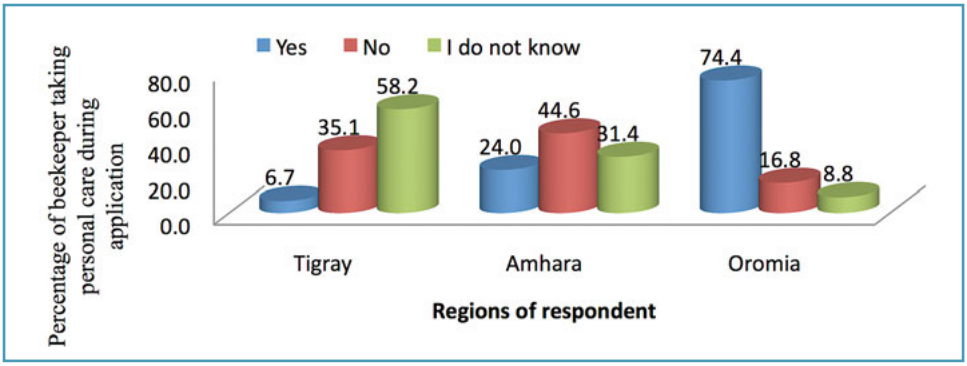

Figure 2. Response to personal protection requirements during herbicide application, by region.

4.3.4. Training on herbicide use

Figure 3 below depicts the proportion of respondents who have participated in trainings on the use of herbicides. The figure shows that 96% (Tigray), 80.3% (Amhara), and 62.8% (Oromia) of the respondents have attended training programs in their respective regions.

Examination of the level of awareness of respondents on rate of application of herbicides showed that 88.9% and 82.2% of respondents in Tigray and Amhara Regions gave a "no" answer, respectively, while 75.5% of respondents in Oromia Region gave a "yes" answer (see Figure 4).

Farmers' knowledge about rate of application of herbicides was also assessed, with due consideration of their level of education. The results revealed that 46.7% of those with elementary education knew about rate of application of herbicides, while 33.7% of them do not. Of the non-educated respondents, 42.6% do not know about rate of herbicide application (see Table 11).

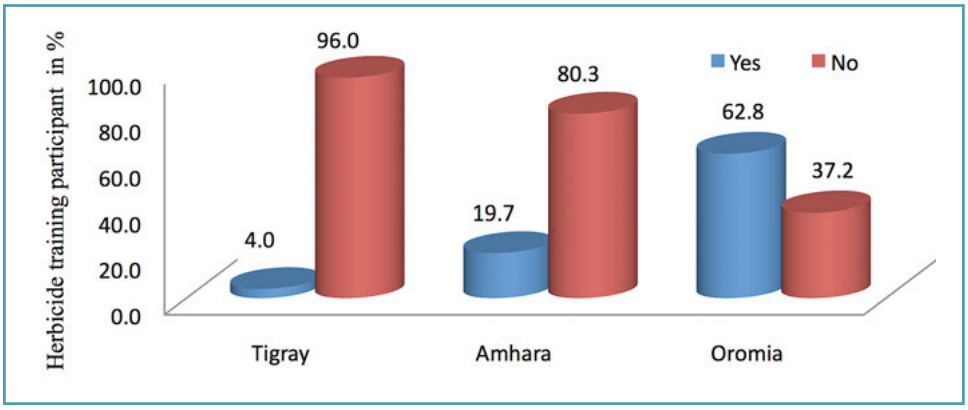

Figure 3. Proportion of respondents who have participated in herbicide training, by region.

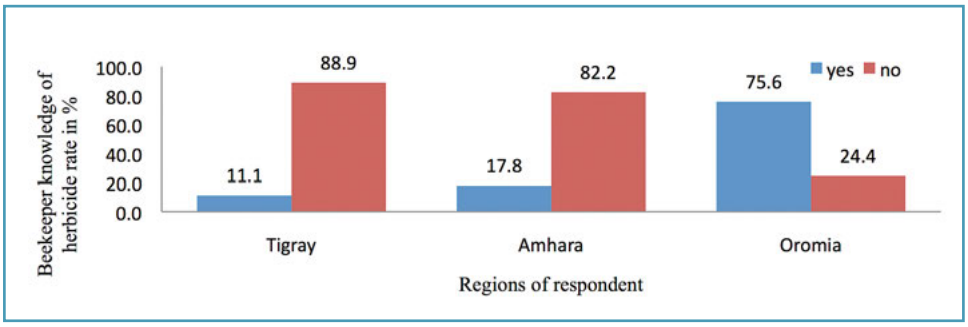

Figure 4. Proportion of respondents who have knowledge about rate of herbicide application, by region.

Table 11. Respondents' knowledge about rate of herbicide application, based on educational status

Educational status	Knowledge on dose/rate of herbicide					
	Yes		No		Total	
	n	N %	n	N %	n	N %
No education	47	17.3	225	42.6	272	34.0
Basic education	73	26.8	94	17.8	167	20.9
Elementary	127	46.7	178	33.7	305	38.1
High school	21	7.7	27	5.1	48	6.0
Diploma and above	4	1.5	4	0.8	8	1.0
Total	272	100.0	528	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

4.4. Herbicide Effect on Non-target Organisms

Results of analysis of data on knowledge of respondents about side effects of herbicides indicated that 70.5% and 48.9% of those in Amhara and Tigray Regions knew the undesirable side effects of herbicides on their bees only, respectively. In Oromia, 42% stated that they knew the side effects of herbicides on bees as well as on humans, and 31.6% in Oromia also knew the effects on animal health (see Table 12).

Examination of trends in bee poisoning during the past five years in the three regions indicated that 86.2% of the respondents stated that there was no poisoning of bees by herbicides in Tigray, while 62.8% and 97.6% of respondents reported bee poisoning in Amhara and Oromia Regions respectively, during the past few years (see Figure 5).

Effects of herbicides on bee colonies during the 2015 crop season were also examined separately by respondents. Accordingly, 88.4% and 75.4% of respondents in Oromia and Amhara Regions respectively indicated that there was herbicide poisoning in the regions. However, 55.1% of bee keepers in Tigray responded that there was no poisoning of bees by herbicides in the region (see Figure 6).

Table 12. Knowledge of respondents of the effects of herbicides on bees, public health, and environment, by region

Side effect of herbicides	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
On bees only	110	48.9	229	70.5	66	26.4	405	50.6
On bees and human health	64	28.4	56	17.2	105	42.0	225	28.1
On bees, human health, and animal health	47	20.9	39	12.0	79	31.6	165	20.6
Other	4	1.8	1	0.3	0	0.0	5	0.6
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

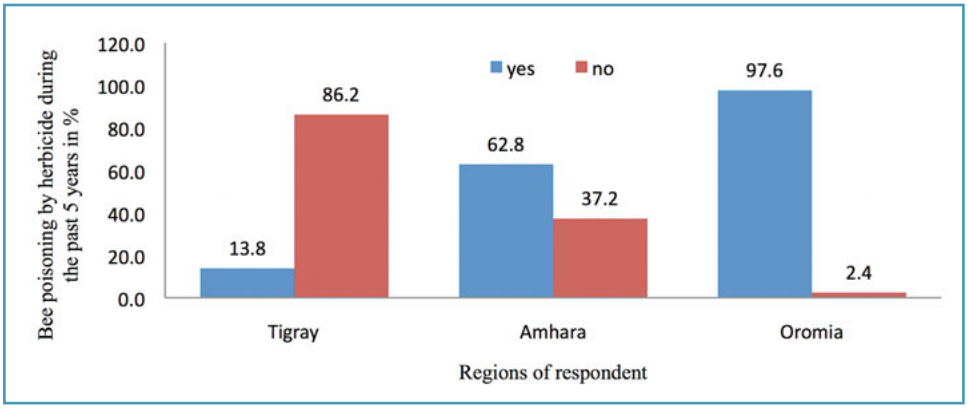

Figure 5. Respondents on bee poisoning by herbicide application during the past five years, by region.

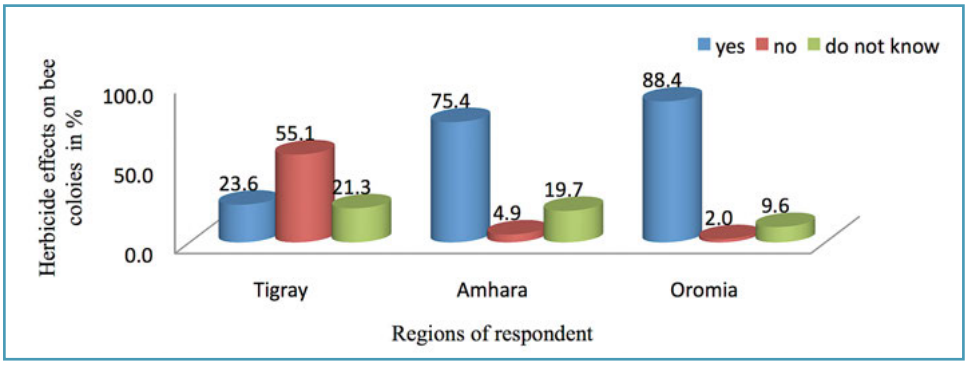

Figure 6. Respondents on the effects of herbicides on bee colonies in 2015 crop season, by region.

Figure 7 shows respondents' perception of the level of severity of damage by herbicides on bees in the three regions. Damage on bees was perceived to be "very severe" in Oromia (49.2%) followed by Amhara (30.2%). Only 5.2% of respondents in Tigray said damage was "very severe," perhaps due to abandonment of herbicide use by the majority of smallholders there.

When asked about the kind of effects herbicides had on bee colonies, 50.4% of respondents in Oromia reported that herbicides resulted in death of bees, while 35.7% stated that herbicides cause absconding of bee colonies in Amhara Region. The response about decrease of bee colonies is roughly similar in the three regions (see Figure 8).

However, the response to a yes/no question on the side effects of herbicide on bees resulted in 91.6% and 55.4% "yes" answers in Oromia and Amhara Regions, respectively, and a 91.6% "no" answer in Tigray (see Table 13).

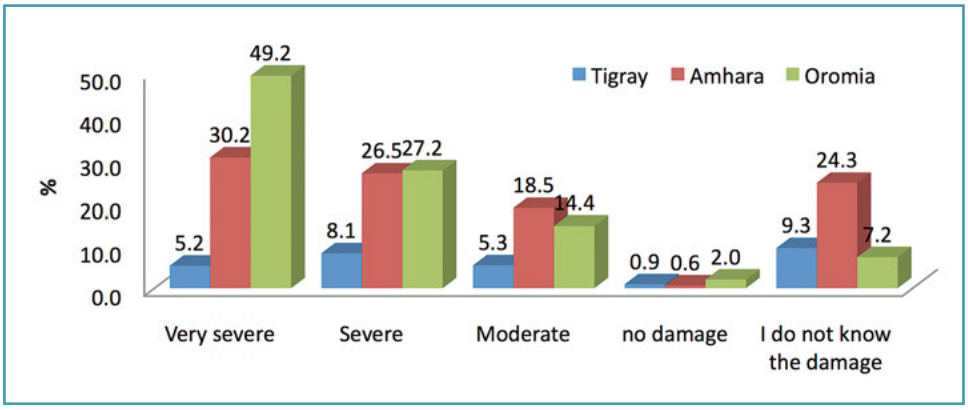

Figure 7. Respondents on level of severity of herbicide effects on bees, by region.

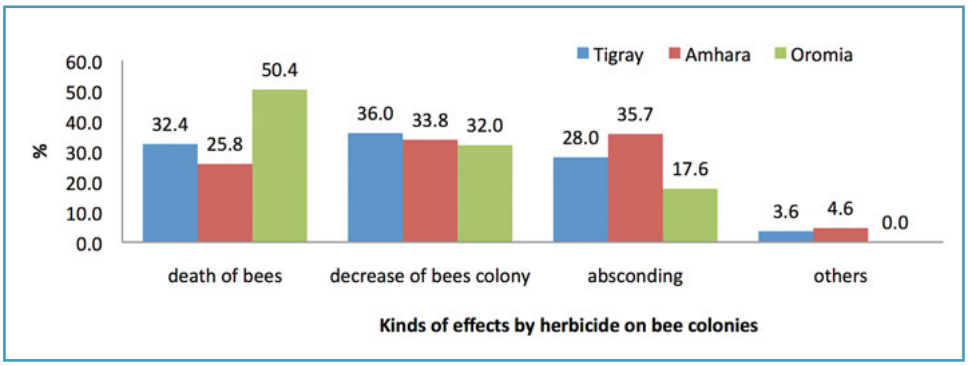

Figure 8. Respondents on the kinds of effects of herbicide on bee colonies, by region.

Table 13. Respondents on bee colonies, by region

Does herbicide affect bees?	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Yes	19	8.4	180	55.4	229	91.6	428	53.5
No	206	91.6	145	44.6	21	8.4	372	46.5
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

Table 14 depicts that 75.6% of respondents in Tigray reported that the number of bee colonies has increased in the past five years. On the other hand, 84.3% and 97.2% of respondents in Amhara and Oromia Regions, respectively, stated that the number of bee colonies has declined over the last five years.

4.4.1. Bee populations and honey harvest over five years

Analysis of data on the number of bee colonies and the amount of harvested honey in Endamekhoni *woreda*, Tigray Region over the past five years (2010–2014) reveals that there was an increasing trend, both in the number of bee colonies as well as in the amount of honey produced over the last five years, except for a slight decline in honey harvest in 2014 (see Figure 9).

A similar examination of the number of bee colonies and the amount of honey harvested in the Amhara Region over the last five years (2010–2014) shows a more or less declining trend, both in the number of bee colonies as well as honey harvest (see Figure 10).

Figure 11 shows data on the number of bee colonies and the amount of honey harvested in Oromia Region over the five years (2010–2014). Examination of the data indicates that there was a decline, both in the number of bee

Table 14. Respondents on effects of herbicides on bee colonies during the past five years, by region

Bees colonies in last five years	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Increased	170	75.6	37	11.4	7	2.8	214	26.8
Decreased	48	21.3	274	84.3	243	97.2	565	70.6
No change	5	2.2	9	2.8	0	0.0	14	1.8
Do not know	2	0.9	5	1.5	0	0.0	7	0.9
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

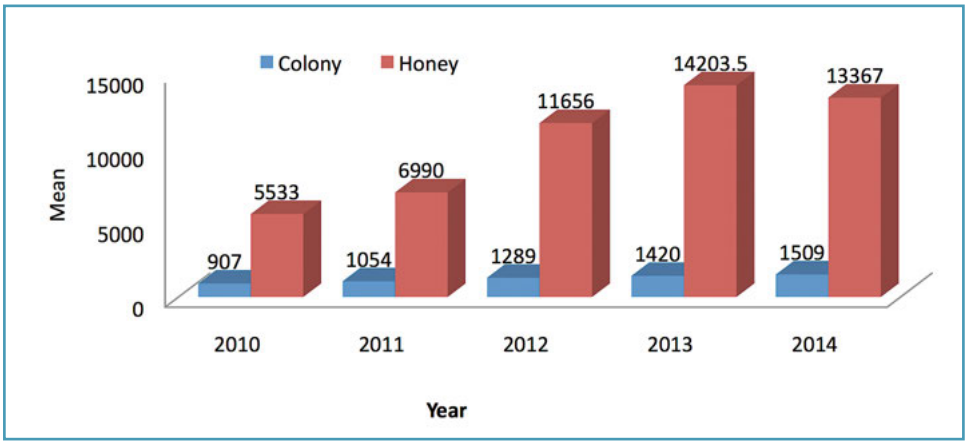

Figure 9. Number of bee colonies and amount of honey harvested (kg) in Endamekhoni **woreda**, *Tigray Region during 2010–2014.*

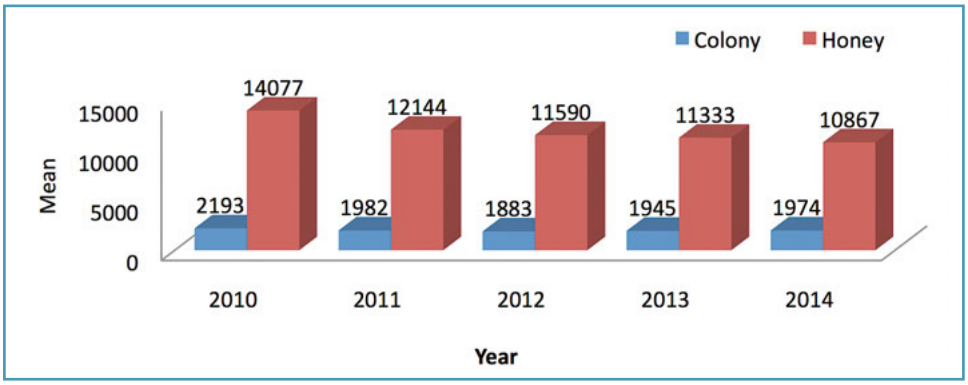

Figure 10. Number of bee colonies and amount of honey harvested (kg) in Dangila **woreda**, *Amhara Region during 2010–2014.*

colonies (gradual) as well as in the amount of honey. The decline in the amount of honey was more drastic, declining by almost half, from 14,097 kg in 2010 to 7,950 kg in 2014.

4.5. Beekeepers' Knowledge of Bee Forages on Their Farms

Assessment of knowledge of respondents of bee forages in wheat fields in the respective *woredas* in Tigray, Amhara, and Oromia Regions (see Table 15) resulted in a "yes" answer at the rate of 94.2%, 95.4%, and 98.4%, respectively.

4.5.1. Herbicide effect on bee forages

As shown in Figure 12 below, 97.2% and 84% of respondents in Oromia and Amhara Regions respectively believe that herbicides have undesirable effects on bee forages, whereas 56.4% of them responded the opposite in Tigray Region.

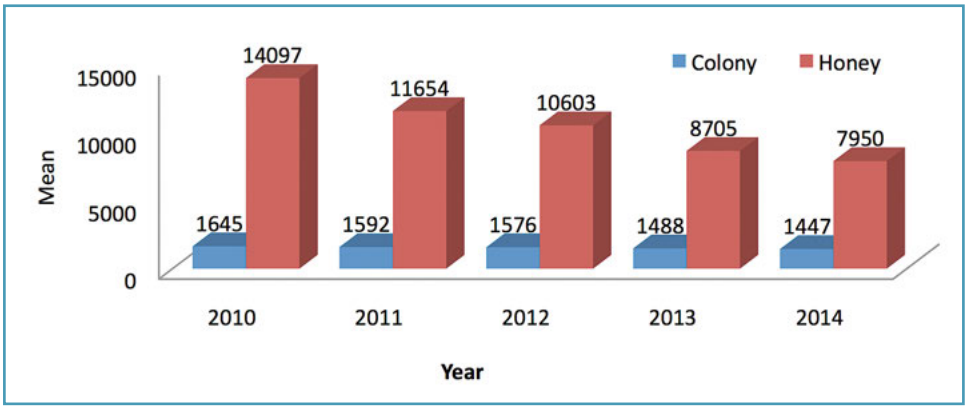

Figure 11. Number of bee colonies and amount of honey harvested (kg) in Agarfa woreda, Oromia Region during 2010–2014.

Table 15. Respondents on knowledge of bee forages in wheat fields, by region

Knowledge of bee forages in their wheat fields	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Yes	212	94.2	310	95.4	246	98.4	768	96.0
No	12	5.3	14	4.3	2	0.8	28	3.5
None	1	0.4	1	0.3	2	0.8	4	0.5
Total	225	100.0	325	100.0	250	100.0	800	100.0

Where n is number of respondents and N% is percentage of respondents.

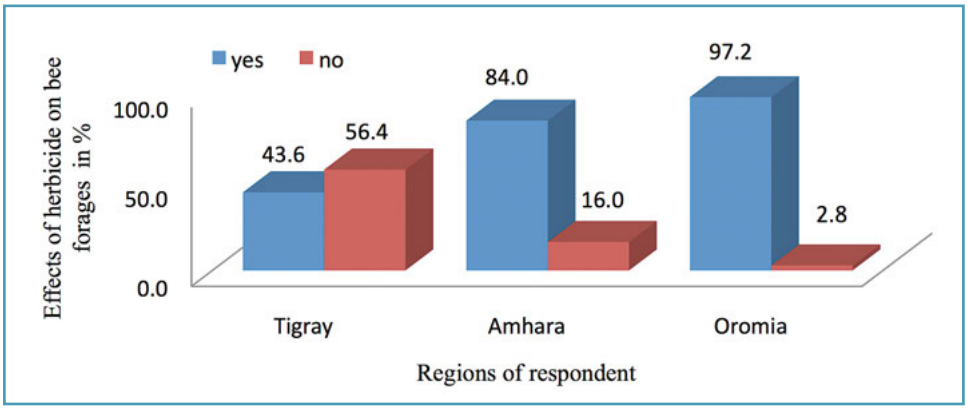

Figure 12. Respondents on the extent of damage by herbicides on bee forages, by region.

In Oromia, 73.6% of farmers felt that the magnitude of damage to bee forages resulting from herbicide application was very severe, while 35.1% and 34.2% of farmers in Amhara Region stated that herbicide damage to bee forages was very severe and severe, respectively. In Tigray, however, 49.8% of respondents reported that they do not know the level of damage (see Table 16).

Figure 13 illustrates farmers' response to the disappearance of bee forages due to herbicide application. Of the total number of interviewees, 96.4% and 79.4% in Oromia and Amhara Regions respectively reported that there are species of bee forages that disappeared due to herbicide effects, but 52.4% of the respondents in Tigray gave a "no" answer.

4.6. DA-facilitated Extension Support in Herbicide Use by Smallholders

According to the guideline for the establishment of farmers/pastoralists training centers (F/PTC) by the Ministry of Agriculture (MoA) of Ethiopia and the Regional Bureaus of Agriculture, there should be three DAs at *kebele* level with the qualification of a diploma in plant science, animal science, or natural resources. Those DAs with diplomas in animal science or plant science are expected to provide extension services in beekeeping and herbicide management, respectively, to smallholder farmers in each *kebele*. Results of findings on the number and characteristics of DAs and the services they render are presented as follows.

Of the total number of DAs interviewed in each sample *woreda*/*kebele* of each region, 70% of them in Tigray were females and 71.4% and 53.8% were males in Amhara and Oromia Region, respectively (see Table 1).

The educational level of DAs varies from diploma to first degree. The diplomas obtained include tenth grade complete plus two years training (10+2), 10+3, and 12+3 (twelfth grade complete plus three years). Out of the total number of interviewed DAs with diplomas, 49.0% of them have 10+3, 9.8% have 10+2, while 15.7% of them have

Table 16. Perceived level of damages by herbicides on bee forage, by region

Level of damage on bee forage	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Very severely damaged	43	19.1	114	35.1	184	73.6	341	42.6
Severely damaged	37	16.4	111	34.2	47	18.8	195	24.4
Moderately damaged	17	7.6	49	15.1	11	4.4	77	9.6
No damage	16	7.1	0	0.0	1	0.4	17	2.1
I do not know the level	112	49.8	51	15.7	7	2.8	170	21.2
Total	225	100	325	100	250	100	800	100

Where n is number of respondents and N% is percentage of respondents.

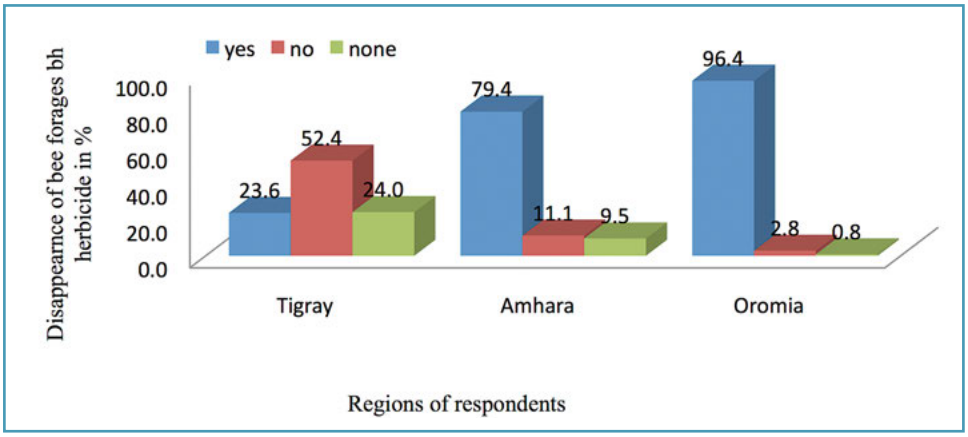

Figure 13. Response on disappearance of bee forages due to herbicide applications, by region.

12+3. Those who have a first degree totalled 25.5%; 57.1% of those were in Amhara Region (see Table 17).

Most of DAs' knowledge and skills originated from the ATVET colleges where they were trained in three major subjects: plant science, animal science, and natural resources management. Their assignment at each FTC was more or less in line with the guideline for DA training for FTCs where three DAs, one from each area of specialty, are assigned to each *kebele*. However, although circumstances show a need for the assignment of bee technicians and apiculture professionals for each *kebele* or for a cluster of up to three *kebeles*, these are largely lacking. Among the interviewed DAs in the three regions, 37.3% of them are specialized in crop/plant science, 35.3% of them are specialized in animal science, and 21.6% of them are specialized in natural resources management. The remaining (5.9%) of them are specialized in others fields (cooperatives, irrigation technicians, and eco-tourism) (see Table 18).

Table 17. Level of education of DAs, by region

Level of education at the time of employment	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
10+2 diploma	3	17.6	2	9.5	0	0.0	5	9.8
10+3 diploma	9	52.9	5	23.8	11	84.6	25	49.0
12+3 diploma	4	23.5	2	9.5	2	15.4	8	15.7
First degree and above	1	5.9	12	57.1	0	0.0	13	25.5
Total	17	100	21	100	13	100	51	100

Where n is number of respondents and N% is percentage of respondents.

Table 18. Field of specialization of DAs, by region

Field of specialization	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Crop/plant science	5	29.4	8	38.1	6	46.2	19	37.3
Animal science	7	41.2	8	38.1	3	23.1	18	35.3
Natural resources management	5	29.4	2	9.5	4	30.8	11	21.6
General agriculture	0	0.0	0	0.0	0	0.0	0	0.0
Other	0	0.0	3	14.3	0	0.0	3	5.9
Total	17	100.0	21	100.0	13	100.0	51	100.0

Where n is number of respondents and N% is percentage of respondents.

4.6.1. Knowledge and perceptions of DAs about herbicide effects on bees

DAs are expected to disseminate or provide agricultural knowledge and technical advisory services to smallholder farmers to enhance agricultural production and productivity. As part of this, federal and regional agricultural offices and any responsible bodies are also expected to offer training in different disciplines, including beekeeping practice, for DAs to update and enhance their knowledge and skills so as to confidently serve the community and to accomplish their daily responsibilities. In Tigray Region, about 58.8% of the interviewed DA respondents reacted with a "yes" answer, while 41.2% gave a "no" answer to participation in beekeeping training. In Amhara and Oromia Regions, respectively, 52.4% and 76.9% of DAs indicated that they have participated in beekeeping training. The largest number (47.6%) of untrained DAs were found in Amhara Region followed by Tigray (41.2%) and Oromia (23.1%) Regions (see Figure 14).

In connection with the above findings, when asked about whether they were providing training to the beekeepers in their extension service system, 58.8% of the DAs reacted with a "yes" answer, while 41.2% reacted with a "no" answer (see Table 19).

With regards to DAs' knowledge of herbicide poisoning and potential for death of bee colonies, 23.5% answered "yes," while 76.5% answered "no" in Tigray Region. The percentage of "no" answers might be due to the banning of herbicide for the past five years in the region. In Amhara and Oromia Regions, respectively, 85.7% and 100% of DAs indicate that they have a clear knowledge and evidence of herbicide poisoning and death of bees (see Figure 15).

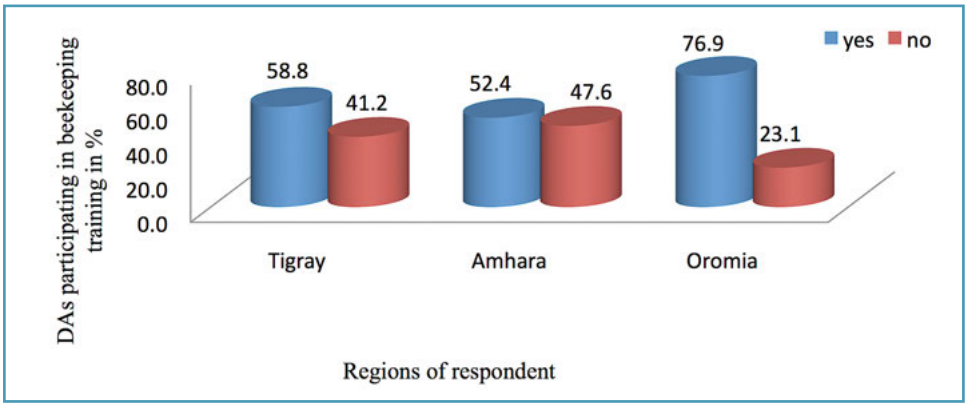

Figure 14. Beekeeping training of DAs, by region.

Table 19. Provision of beekeeping training by DAs, by region

Providing training to beekeepers through DAs	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Yes	11	64.7	7	33.3	12	92.3	30	58.8
No	6	35.3	14	66.7	1	7.7	21	41.2
Total	17	100.0	21	100.0	13	100.0	51	100.0

Where n is number of respondents and N% is percentage of respondents.

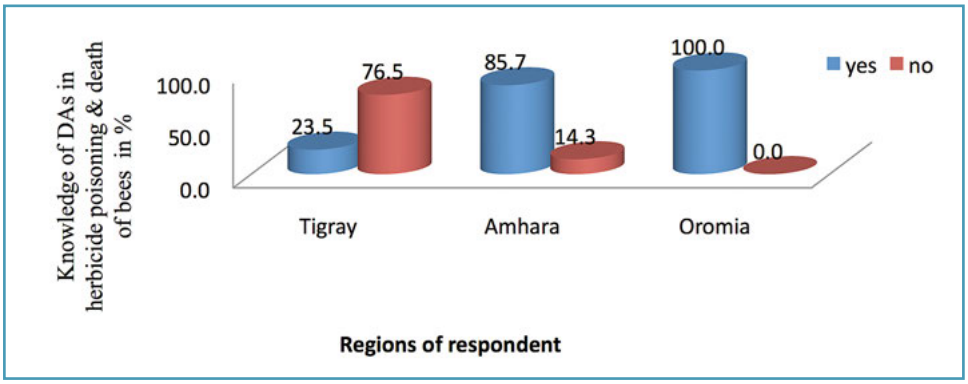

Figure 15. Knowledge of DAs in herbicide poisoning and death of bee colonies, by region.

Of the total number of DAs, 80.4% of them reacted with a "yes" answer, while 19.6% of them reacted with a "no" answer towards beekeepers' absconding problems with their colonies (see Table 20). The absconding of bee colonies might be due to a shortage of bee forages, scarcity of the types of wood in which beehives exist, drought, lack of beekeeping technicians, and lack of a convenient apiary site for bees. Exclusive of Tigray Region, the main reason for bee colonies absconding problem was chemical herbicide application for the purpose of weed control on farms.

Table 20. DAs' perception of absconding problems of bee colonies due to herbicide, by region

Beekeeper absconding problems with their colonies	Region of respondents						Total	
	Tigray		Amhara		Oromia			
	n	N %	n	N %	n	N %	n	N %
Yes	9	52.9	19	90.5	13	100.0	41	80.4
No	8	47.1	2	9.5	0	0.0	10	19.6
Total	17	100.0	21	100.0	13	100.0	51	100.0

Where n is number of respondents and N% is percentage of respondents.

5 LESSONS DRAWN

The following core lessons emanating from field activities and findings in the three selected *woredas*, namely Endamehkoni (Tigray Region), Dangila (Amhara Region), and Agarfa (Oromia Region), were drawn from the study:

- The majority (93.3%) of farmers in Endamehkoni *woreda* of southern Tigray abandoned the use of herbicides about five years ago due to its negative effects on their bee population. The objective was safeguarding their bee colonies from herbicide poisoning. Farmers instead use cheap family labor for hand-weeding on their fragmented and scarce land resources of less than or equal to 0.5 ha per household.

- Well over 70% of farmers in Dangila and Agarfa *woredas* of Amhara and Oromia Regions use 2,4-D and Roundup, and 2,4-D and Palace, respectively. The majority (99.9%) of farmers in Oromia use herbicides on wheat, while 43.4% and 30.2% of farmers in Amhara Region use herbicides on maize and finger millets.

- In Oromia, 99.2% of farmers use herbicides regularly. In Amhara, 37.8% of respondents use herbicides occasionally. In Oromia, 52.8% of farmers apply herbicides once per year and 45.6% of them apply them twice per year, while 49.5% of farmers in Amhara apply herbicides once per year.

- Herbicide guidelines are followed by 55.6% of farmers with elementary education, while 43.2% of them follow guidelines sometimes; 48.2% of farmers with a land holding of greater than 0.25 ha and less than 1 ha follow herbicide use guideline sometimes, while those with a land holding of greater than 2 ha but less than 5 ha always follow herbicide use guidelines.

- The majority (96.9%, 97.8%, and 95.6%) of farmers have a good understanding and recognition of the undesirable effects of herbicides on bees in the three regions. Farmers are aware of personal protection requirements during herbicide application in all the three regions but do not practice them for different reasons.

- Among respondents, 96%, 80.3%, and 62.8% of farmers in Tigray, Amhara, and Oromia, respectively, have attended training programs on the use of herbicides; 86.2% of farmers in Tigray reported no poisoning of bees by herbicides, while 62.8% and 97.6% of farmers reported bee poisoning in Amhara and Oromia respectively during the past few years.

- The number of bee colonies and the honey harvest has increased in Tigray during the past few years, while the number of bee colonies and the honey harvest has declined in Amhara and Oromia over the last five years (2010–2014).

- Among respondents, 96.4% and 79.4% in Oromia and Amhara, respectively, reported that there are species of bee forages that disappeared due to herbicide effects, but 52.4% of farmers in Tigray gave a "no" answer to this question of disappearance of bee forages.

- Among the DAs assigned to each *kebele*/FTC, none of them are skilled or trained in bee technology and pest/pesticide management to provide extension support services to bee keepers/farmers in the three *woredas*. The FTCs are poorly established, and most are seldom functional, lacking the required capacities and enabling environments.

- Of the total number of DAs, 70% in Tigray are females, and 71.4% and 53.8% are males in Amhara and Oromia respectively.

6. CONCLUSION AND RECOMMENDATIONS

The efforts made in the execution of the project work, the lessons learned, and the achievements gained are enormous. There were significant differences among the three selected *woredas* in the three regional states of Tigray, Amhara, and Oromia in terms of herbicide use and management.

In Tigray, the majority of farmers have abandoned the use of herbicides through appeal to the *woreda* office of agriculture and *woreda* cabinet/council, which accepted the farmers' request to protect bee colonies from herbicide poisoning some five years ago. However, abandonment of herbicide use resulted in conflict of interest between neighboring beekeepers and crop growers in the *woreda*, thus requiring conflict management efforts by the *woreda* administration. There is no recommendation from research of any safer herbicide to bees for use on wheat fields as an alternative to 2,4-D to curb bee poisoning to date. Abandonment of the use of herbicides in Endamehkoni, Tigray, might serve as a tentative solution for protecting the livelihood of beekeepers. However, there is a need for a long-lasting strategic intervention that will strike a balance and avoid conflict of interest in beekeeping and crop production among beekeepers/farmers in the *woreda*. Furthermore, the study area in Tigray is a dry-land area characterized by a precarious drought and environmental degradation. Increasing population pressure and associated vegetation changes have resulted in a critical shortage of bee forages, which is a serious threat in the development and promotion of the apiculture sector. Intervention measures must be taken to mitigate the problem, with a focus on bio-intensive IPM and ecological principles and practices in all three regions.

Although there is a longer history of herbicide use in Oromia compared to that of Amhara, herbicides are continuously used in the cereal farming systems in the two selected *woredas* of Amhara and Oromia Regions. The undesirable consequences of herbicides on bee colonies and production/productivity of honey in the two districts were well recognized. The most critical problem in the development and promotion of the apiculture sector in the two regions was the irrational use, or overuse and mismanagement, of herbicides in the cereal farming systems. This misuse has caused bee colony poisoning and undesirable effects on non-target organisms (including crop pollinators), bee forages, and the environment at large. Hence, there is a need for an integrated weed management support system (IWMSS) within the framework of an integrated crop-and-beekeeping system for sustainable crop and honey production for food security and better livelihoods.

Based on our findings, we propose the following specific issues for consideration by the concerned and responsible bodies in the development and promotion of the apiculture sector:

Policy aspect:

- Although there is the Federal Negarit Gazeta (Proclamation No. 660/2009) on Apiculture Resources Development and Protection, there is no legal framework for its implementation. Therefore, there should be a strong national herbicide policy and legal framework that safeguards bee colonies starting with importation, distribution, and use of broad-spectrum herbicides in the cropping systems.

- There is also a need for rules and regulations that could serve as conflict management tools among farmers of different interests in the use of herbicides in each district/region.

Technical aspect:

- There is a need for skill-based capacity-building programs for SMS, DAs, and farmers to introduce a comprehensive package of beekeeping technologies and herbicide management on a regular basis.

- There is a need for initial investment with affordable credit/loans for the purchase of beehives and equipment, with a long-term repayment schedule for sustainable beekeeping programs in the regions.

- Rehabilitation of beekeeping sites and planting of bee forages need be initiated in enclosure areas and water sources/streams, with particular focus on Tigray Region.

- The research, extension, and service support/delivery systems in the introduction and rational use of bee-safe and environmentally acceptable herbicides should be strengthened.

Extension system:

- Although the current organizational structure of the extension system and its approaches at the grassroots (*kebele*) level is very good, the F/PTCs should be capacitated to enable DAs to deliver both theoretical and practical training on beekeeping technologies to beekeepers/farmers, using both traditional and modern beehives.

- DAs should be motivated to undertake assigned duties in awareness creation and technical training of farmers/beekeepers, cooperatives, and farmer unions, with due consideration of women and youth.

In general, we recommend an integrated and sustainable crop-apiculture development strategy based on bio-intensive IPM and ecological principles and practices in the three regions through a system approach to fight system bottlenecks of high levels of illiteracy, inadequate enforcement of policies and legal standards, inadequate safety precautions and safety devices, improper herbicide labelling, and insufficient knowledge for sustainable integrated wheat and honey production and an environmental management system.

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Other chemical (Diazinon) spraying practice to control external parasite of goats in Tigray regional State

Traditional & Modern beehives near home of beekeepers in Amhara regional State

Bee keeper's traditional beehives in Tigray Regional Sate

Bee keeper's modern beehives in Oromia Regional State