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RESEARCH

The impact of tobacco (*Nicotiana tabacum*) farming on the survival of honeybees (*Apis mellifera*) in Nyamakate Communal Area, northern Zimbabwe

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ABSTRACT

The impact of tobacco (*Nicotiana tabacum*) farming on the survival of honeybees (*Apis mellifera*) was investigated through the documentation of mortality of honeybees, the number of trees cut and planted, and agrochemicals used in tobacco farming in Nyamakate Communal Area, Hurungwe District, northern Zimbabwe. The study was conducted in the wet season, i.e. between December 2017 and March 2018 using a stratified random sampling design to sample tobacco farmers and apiculturists. Honeybee mortalities across five sampled villages were significantly different (Kruskal–Wallis χ^2 test = 74.54, df = 4, $p < 0.05$). The survey recorded 14 different agrochemicals that tobacco farmers used in tobacco farming, although the local regulator banned five of them in the 2018 and 2019 agriculture season. All five villages recorded an estimated 5,220 indigenous trees that were cut to cure tobacco whereas 483 *Eucalyptus* trees were planted as part of ongoing reforestation efforts in the district within the study period. It was concluded that tobacco farming negatively impacts honeybees through reduced forage and nesting sites (resulting from deforestation) and increased mortalities from the use of toxic agro-chemicals. There is a need for legislative alignment to ensure effective law enforcement on compliance. Government and partners need to encourage tobacco farmers to plant fast-growing indigenous trees for afforestation and adopt modern technology such as the use of solar-powered tobacco curing barns.

1. Introduction

The need to boost agricultural production has led to an increase in the use of agro-chemicals (Gels et al. 2002; Balasha et al. 2019). However, some of these chemicals are known to reduce honeybees' (*Apis mellifera*) survival and occurrence irrespective of whether they have been used properly or improperly (Porrini et al. 1996; Balasha et al. 2019; Bertomeu-Sánchez 2019). Constant exposure of honeybees to agrochemicals, e.g. carbamate, organophosphate and pyrethroid lead to toxicity and elevated levels of mortality in honeybee colonies (Kearns et al. 1998; Bertomeu-Sánchez 2019). Most of the agrochemicals have compounds that contaminate nectar and pollen, which is a source of food for honeybees (Porrini et al. 1996; Bertomeu-Sánchez 2019). Herbicides which are commonly not toxic to bees destroy many plants that are valuable to honeybees as sources of pollen and nectar (Porrini et al. 1996; Bertomeu-Sánchez 2019). A study in North America revealed that bumble bee (*Bombus* spp.) colonies foraging on contaminated flowers have fewer brood chambers, fewer workers, and reduced total biomass of workers (Gels et al. 2002). Some insecticides have sub-

lethal effects and can result in honeybee colony damage through chronic effects, including compromising the behaviour, health and immunity of bee colonies (Gels et al. 2002; Balasha et al. 2019; Bertomeu-Sánchez 2019). Agro-chemicals have impacts on honeybee ecology in many African countries (Porrini et al. 1996; Tarakini et al. 2021). Poor monitoring and law enforcement worsened the use of some agrochemicals to an extent that some banned pesticides like Acephate, Fenvalerate, Methamidophos, Thiodicarb are still being used in agriculture (Tobacco Industry and Marketing Board 2011; Masvongo et al. 2013). In some countries, legislation is not enforced to ensure environmentally friendly agrochemical use, which poses a great risk to *Apis* spp. (Tobacco Industry and Marketing Board 2011; Masvongo et al. 2013).

Tobacco (*Nicotiana tabacum*) farming requires a substantial amount of wood for several purposes, i.e. wood material required for the preparation of tobacco before curing, construction of curing barns as well as firewood for curing (Tobacco Industry and Marketing Board 2011; Masvongo et al. 2013).

Research has shown that in Kenya on average subsistence tobacco farming requires about 60 mature indigenous trees per farmer per season to cure the crop (Kerata 1999). Again in Kenya, tobacco farmers continued to use more indigenous trees than exotic trees after some general perception that tobacco cured with exotic trees produces undesired aroma (British American Tobacco 1977; Ministry of Economic Planning 1977). The reluctance by smallholder farmers in implementing afforestation and reforestation programmes poses a threat to honeybees' conservation since trees in forests forms a major source of bee habitat and forage (Alkire and Foster 2011; Nyatsande et al. 2014; Tarakini et al. 2021).

In Zimbabwe, most communal farmers have shifted to intensive tobacco farming as an alternative agribusiness venture (Cole and Cole 2006; Mavedzenge et al. 2008). However, tobacco farming seems to have negative impacts on the survival and persistence of honeybees in the natural environment and the possibility of effective apiculture ventures as a source of livelihood by local communities (Mujuni et al. 2012). Additionally, honeybees' conservation has a spill-over effects where it directly promotes woodlands conservation and watershed management among other benefits (Gibbs and Muirhead 1998). Although much information on the economic significance of tobacco farming is known, a gap remains when it comes to its impacts on naturally occurring honeybees (Masvongo et al. 2013).

In Hurungwe District, northern Zimbabwe, most communal farmers depend on firewood in curing their tobacco crop. As of 2006, about nine out of ten communal farmers were involved in tobacco farming (Shumba and Whingwiri 2006). Consequently, an estimated 180,000 trees are cut per year in Zimbabwe (Masvongo et al. 2013; Mujuru and Oeba 2019). The Government of Zimbabwe together with local tobacco companies are calling for a zero-tolerance to deforestation and have launched campaigns against environmental degradation emanating from tobacco farming. To combat the challenges of deforestation, companies are distributing *Eucalyptus* seeds to farmers to meet the future needs of firewood in tobacco curing. Besides the economic profitability of *Eucalyptus* trees, some concerns are that they have the potential to alter the prevailing natural ecosystem, hence the need to consider ecosystem well-being before growing them. The *Eucalyptus* spp. require a lot of nutrients, secrets allelochemicals that exhaust soil nutrients and decreases crop production. Indigenous trees should be given more priority than exotic trees in reforestation and afforestation programmes. Currently, tobacco contractors provide coal to farmers to mix with indigenous firewood to cure tobacco. Despite the need and emphasis, communal farmers largely have not yet established viable *Eucalyptus* woodlots due to unavailable land for woodlots, limited fencing materials to protect planted trees and limited extension services to educate farmers on afforestation (Masvongo et al. 2013; Mujuru and Oeba 2019). Consequently, small scale tobacco farmers continue to rely on naturally growing indigenous trees for tobacco curing. Therefore, the objective of this study was to investigate tobacco farming practices and their possible impact on honeybees' conservation in the Nyamakate Communal Area (NCA), Hurungwe District, northern Zimbabwe.

2. Materials and methods

2.1. Study area

This study was conducted in the NCA in Hurungwe District, Mashonaland West province in northern Zimbabwe (Figure 1). Hurungwe District lies between latitude 16° 30' 00" and longitude 29° 30' 00" South and East of the Equator, respectively. NCA lies 60 km north of Karoi town. Hurungwe District is characterised by diverse land uses including small-scale communal farming, resettled farming, medium and large-scale commercial farming, urban centres, safari and national park areas. NCA shares boundaries with Mana Pools National Park, Hurungwe Safari Area and Charara Safari Area (Chenje et al. 1998; Magadza 2010). NCA is in agro-region III with an annual rainfall of between 500 and 750 mm characterised by mid-season dry spells (Chenje et al. 1998). The area experiences high temperatures, with mean maximum and minimum temperatures ranging between 30°C and 22.5°C in October and July, respectively (Chenje et al. 1998). NCA has an altitude ranging between 1000 and 1,160 m above sea level (ZIMVAC 2010). Its soils are characterised by ferisialitic and pockets of lithosol soils and local farmers effectively grow maize (*Zea mays*), tobacco, sugar beans (*Phaseolus vulgaris*), sorghum (*Sorghum bicolor*) and groundnuts (*Arachis hypogaea*) (Chenje et al. 1998). NCA is a multicultural society with a population estimate of 7,738 comprising 2,908 households organised into 48 villages (Zimstat (Zimbabwe National Statistics Agency) 2012; ZIMVAC 2010).

NCA has several non-perennial streams that run through the area and areas along streams form good habitats for honeybees. Nyamakate and Rukomechi are the major rivers that used to be perennial before they were silted up. The Miombo woodland is the most dominant woodland type in the communal area. The area is extensively dominated by Msasa (*Brachystegia spiciformis*) and Prince of Wales' feathers (*Brachystegia boehmii*) (Chenje et al. 1998). These forests are gradually disappearing due to deforestation and are being replaced by increasing numbers of *Acacia* species (ZIMVAC 2010).
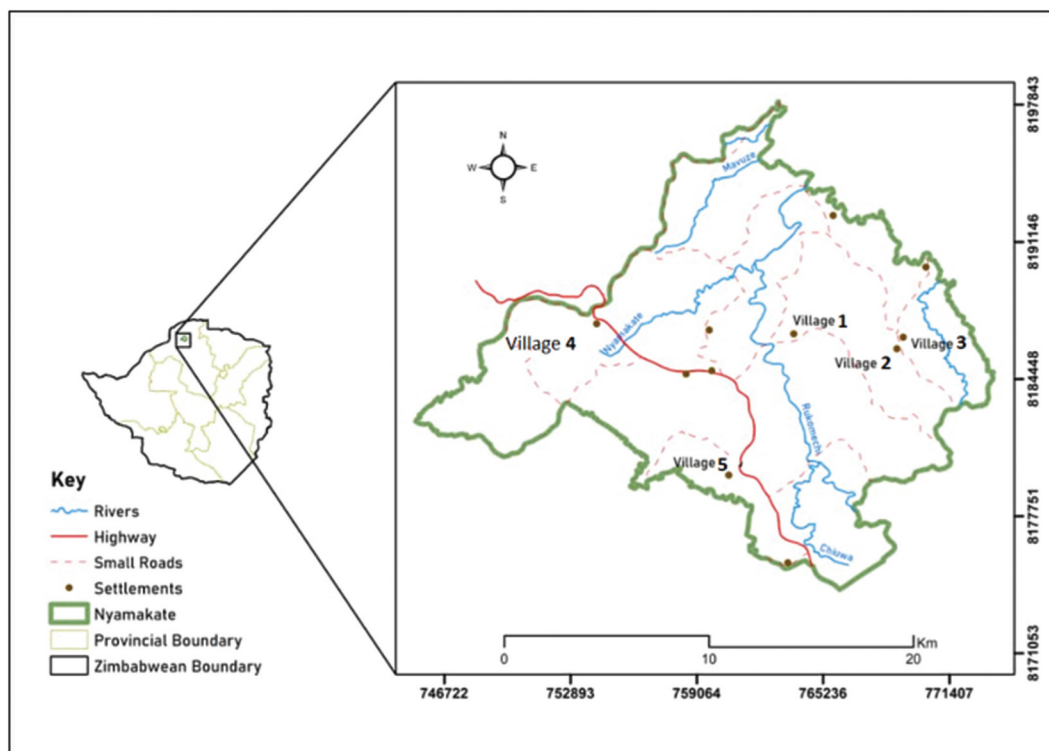
Figure 1. Nyamakate Communal Area in Hurungwe District, northern Zimbabwe, showing the study villages numbered 1–5.

2.2. Research design and data collection

A stratified random sampling design was used in this study. A two-stage selection approach was used to randomly select the study villages. The first stage identified five villages within NCA using the Tobacco Industries and Marketing Board (TIMB) register. We randomly selected villages from the 48 villages in NCA, i.e. Villages 27, 28, 29, November and India, hereafter numbered 1, 2, 3, 4 and 5, respectively. The second step involved the use of TIMB farmers' registers to identify a list of all small-scale tobacco farmers in the targeted villages. From the alphabetical list, every tenth registered farmer was selected for sampling in each village. Twenty farmers were randomly selected from the five villages totalling 100 farmers drawn for an in-depth study. The selected farmers were involved in growing tobacco and keeping bees as part of mixed farming. A structured questionnaire was used in collecting data from stratified randomly selected farmers. We introduced the questionnaires to the targeted farmers in their respective villages and households. The questionnaires were completed by the head of the family or the registered farmer in each targeted household. Data collected through structured questionnaires included: quantities of trees used to cure tobacco per season, quantities of established colonies, number of *Eucalyptus* trees planted, area (Ha) cleared to grow tobacco and type of agrochemicals used. A checklist of recommended agrochemicals by Tobacco Research Board Kutsaga and a list of banned pesticides under International Conventions were collected and cross-referenced with

what farmers were using (UTZ 2015; *R. Mavuka personal communication to J. Chakuya in 2018*; Tobacco Research Board Kutsaga 2016). The secondary data for each targeted households' type of agrochemicals used, the total area under tobacco farming, the number of trees used in curing tobacco was obtained from the Tobacco Research Board (TRB Kutsaga), TIMB, district agricultural extension services office and tobacco contractors companies farmers' records registers (Tobacco Research Board Kutsaga 2016).

2.2.1 Assessment of honeybee colonies occurrence and mortalities

A monitoring protocol was adopted to assess bee colonies occurrence and mortalities (Table 1). Within each selected village, five farmers growing tobacco and keeping bees at the same time were randomly sampled. From the five selected farmers, four of each farmers' beehives were sampled yielding a total of 100 beehives that were sampled. To ensure homogeneity (in terms of colony strength) between them and those of other stations, standard Kenyan top bar hives were used, and beehives were

Table 1. Assessment protocol for honeybee mortality.

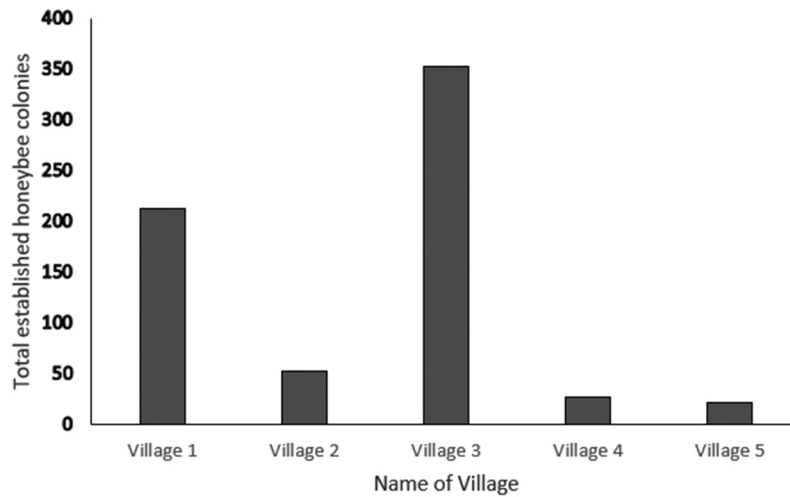| Variable	Measurement unit/approach
Hives per station	Two per station
Dead bee collection traps	Underbasket
Used matrices	Dead bees
Frequency of sample collection	Weekly
Critical mortality threshold	250 bees/week/station

Figure 2. Number of established honeybee colonies in different villages.

regularly checked for sanitary purposes. Bee station distances varied from one farmer to the other and from one village to the other since different farmers had sited their beehives differently. Honeybees colony strength was estimated using the Liebefeld colony size estimation method (Gerig 1983), and the strength was assumed to be uniform across all villages with each colony estimated to have an average of 50,000 *A. m. scutellate* bees species. A modified underbasket developed from Gary's bees trapping cage which is regarded as being more efficient in retaining dead bees and protecting them from predation (Celli and Maccagnani 2016) was used in this study. A total of 100 underbaskets were fitted to study beehives and were checked once a week for 30 days and the numbers of dead bees were recorded on a data collection sheet. Honeybees' mortalities were assessed to check if the rates were not exceeding the critical threshold of 250 bees per week per station (Porrini et al. 2002; Celli and Maccagnani 2016). Honeybee mortality data were collected in the rainy season between December 2017 and March 2018 to ensure maximum effects of agrochemical poisoning. Further, deforestation from tobacco-related farming practices were collected.

2.3. Data analysis

Descriptive statistics were used to summarise the collected data. A Kruskal-Wallis χ^2 test was used to analyse if there were any significant differences in honeybee mortalities across the five sampled villages. Data were tested for normality using the Shapiro-Wilk test and respective analyses were conducted

guided by data conformity to the respective tests (Shapiro and Wilk 1965). Further, a comparison of banned and non-banned agrochemicals in use was conducted based on agro-chemical databases from Tobacco Research Board and World Health Organisation (WHO), Food Agricultural Organisation (FAO) and European Union (EU). The Factor Analysis of Mixed Data (FAMD) and Mixed Factor Analysis (MFA) was used to analyse different agrochemical usage within different villages. Further, correlation analysis was carried out on the number of trees used, the quantity of firewood used, the number of *Eucalyptus* planted and area under tobacco and the number of bee mortalities. All analyses were conducted using R software (R Core Team 2020).

3. Results

3.1. The occurrence of honeybee colonies and bee mortalities

The highest number of honeybee colonies were recorded in Village 3 with the least in Village 4 (Figure 2). No significant differences were recorded in honeybee mortalities across the five sampled villages (Kruskal-Wallis χ^2 test = 74.54, df = 4, $p > 0.05$). The study revealed more honeybee colonies in Village 3 (Figure 2). Village 3 recorded more than 250 honeybee mortalities per week (Figure 3).

Villages 1, 4 and 5 recorded honeybee mortalities below 200 honeybees per week (Figure 3). Many trees were cut to clear tobacco farming land and to acquire firewood for tobacco curing. The trees cut to clear tobacco production area and firewood for tobacco curing were significantly correlated (Pearson's correlation test: r = 0.74, n = 100, $p < 0.05$; r = 0.42, n = 100, $p < 0.05$). An increase in firewood collection
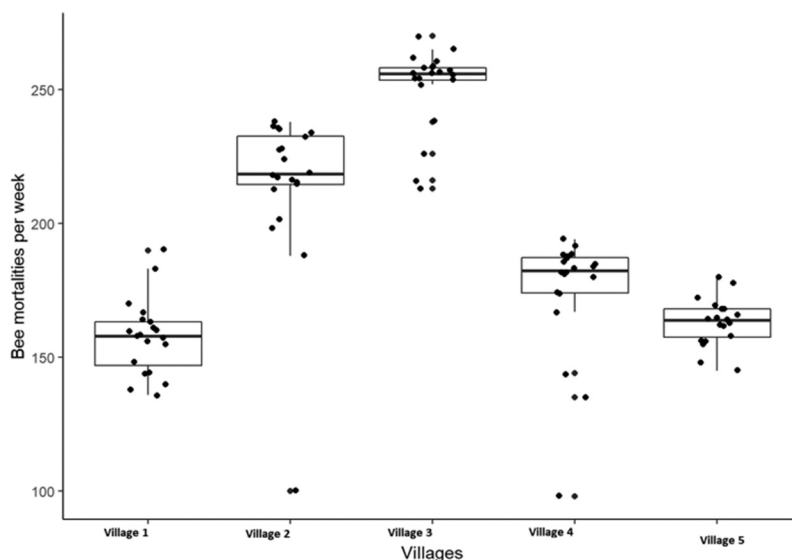
Figure 3. Honeybee mortalities per week.

resulted in bigger areas cleared and the study recorded a significant correlation of firewood collected and areas cleared (Pearson's correlation test: r = 0.36, n = 100, *p* < 0.05) (Figure 4).

Honeybee mortalities were significantly correlated with the number of trees cut for tobacco curing (Pearson's correlation test: r = 0.63, n = 100, *p* < 0.05) (Figure 4). In addition, honeybee mortalities were significantly correlated with the area cleared for tobacco farming and firewood cut to cure tobacco (Pearson's correlation test: r = 0.64, n = 100, *p* < 0.05; r = 0.26, n = 100, *p* < 0.05) respectively (Figure 4).

3.2. Impact of tobacco farming on woody vegetation and the occurrence of honeybee colonies

Indigenous trees were recorded as being intensively used in tobacco farming with Village 3 recording the greatest trees cut to cure tobacco standing at 1,802 trees cut within one season (Figure 5). Village 2 recorded the highest number of *Eucalyptus* trees planted in the 2018–2019 season, having 114 trees planted (Figure 5). All five villages combined recorded 5,220 indigenous trees that were cut to cure tobacco and a total of 483 *Eucalyptus* trees were planted as part of the reforestation programme within the 2018–2019 season. Villages 1 and 3 recorded high numbers of trees cut to cure tobacco and the same villages had high numbers of honeybee colonies observed (Figure 5).

3.3. Tobacco farming and use of agro-chemicals

The study revealed 14 different types of agrochemicals that tobacco farmers used in tobacco production. All the five sampled villages were still using the

banned agrochemicals, and in particular, Monocrotophos and Methamidophos (Figure 6a). Villages 1, 2 and 3 had the greatest usage of banned agrochemicals (Figure 6b).

4. Discussion

This study showed an increase in land cleared particularly to expand tobacco farming. Tobacco farming is one of the major cash crops grown in the NCA with a negative impact on honeybees' survival. Honeybees either managed or wild have been reported to be negatively impacted by the destruction of natural habitats, fragmentation of their natural and semi-natural habitats (Tarakini et al. 2021). Destructive practices involve the massive clearance of huge forests or lands to allow selective production of crops and this limits honeybees nesting ability. In particular, tobacco farming destroys honeybee habitat in three major forms, i.e. through the increased number of trees cut to cure tobacco, trees cut in the construction of bans and clearance of virgin fertile lands. The number of trees cut to cure tobacco was noted to be correlated to areas cleared. In most cases, communal farmers cut trees to clear forested lands for tobacco farming and to obtain firewood and other uses (Tarakini et al. 2021). Many trees were cut for firewood, farming land clearance and other domestic uses and this directly resulted in reduced honeybees' habitat and forage grounds. In this regard, the study showed that honeybees mortalities were significantly correlated with the number of trees cut for tobacco curing. Due to close interaction with the forest for forage, honeybees can be regarded as good bioindicators of the state of the environment. A decline in plant diversity at a local scale would likely result in a decline in honeybees and other pollinators
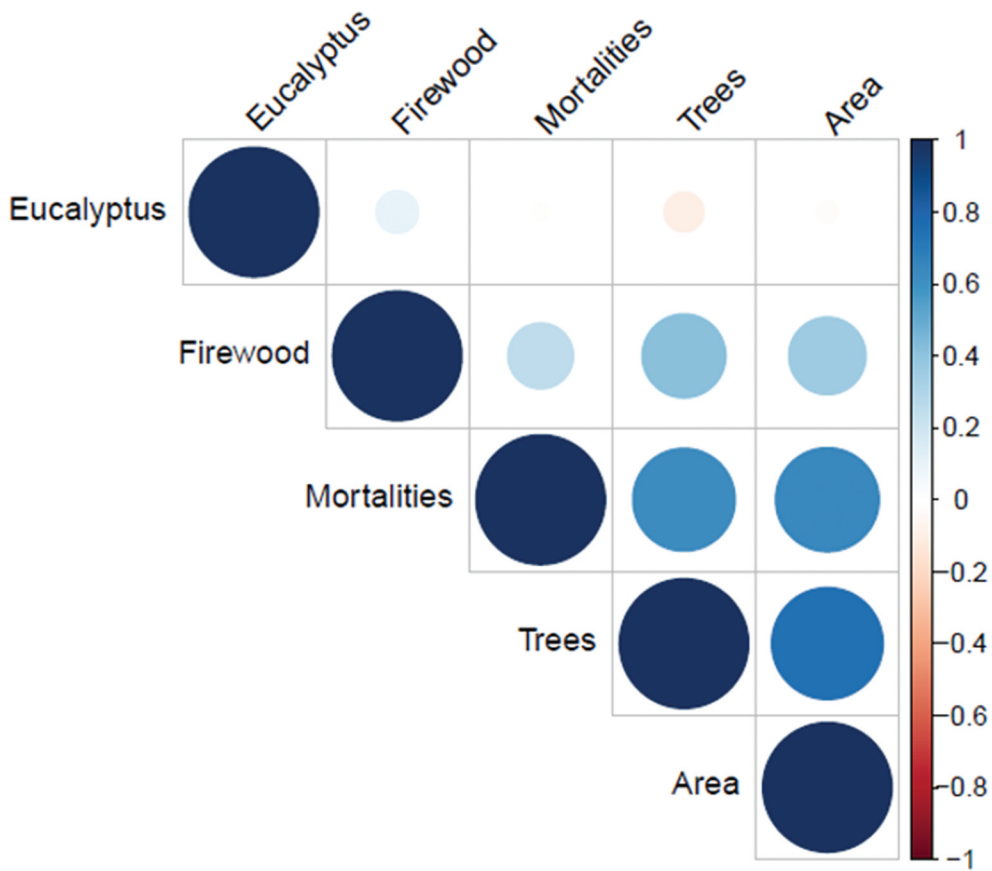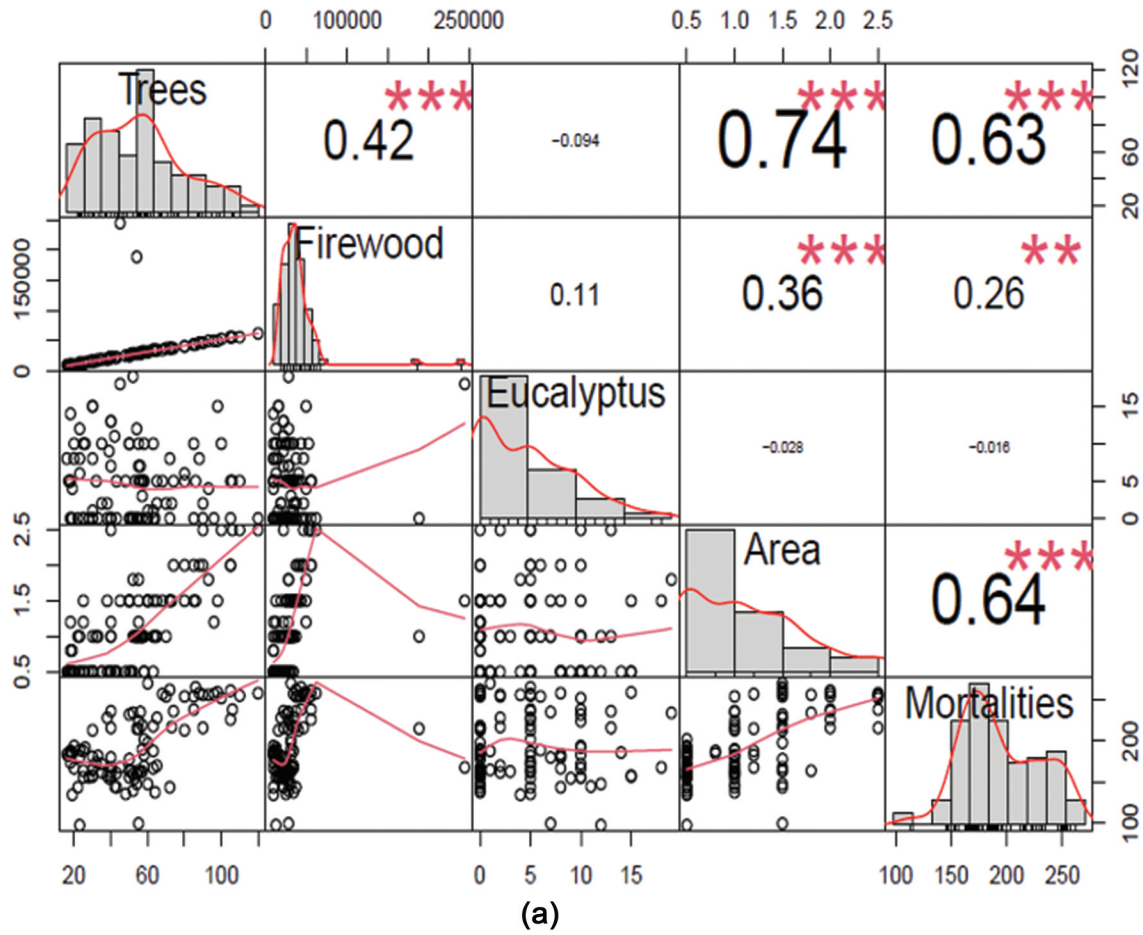
(a)

(b)

Figure 4. (a): Correlation matrix showing the magnitude of significance for the number of trees used, the quantity of firewood used, number of *Eucalyptus* planted, area under tobacco and the number of honeybee mortalities. (b): Correlation plot for the number of trees used, the quantity of firewood used, number of *Eucalyptus* planted, area under tobacco and the number of honeybee mortalities.
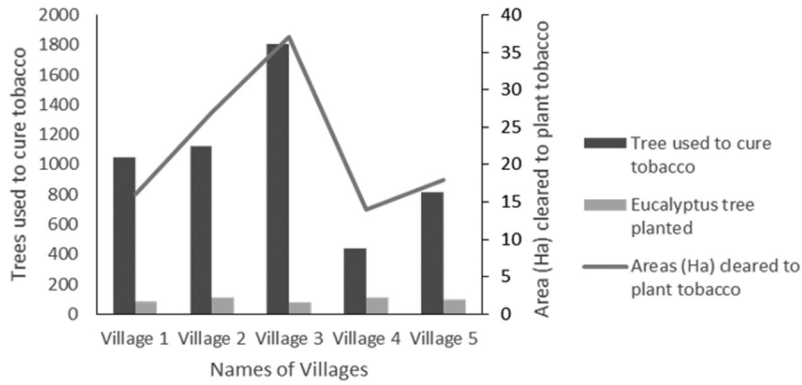
Figure 5. Quantities of trees and area cleared during the 2017 to 20,018 tobacco farming season.

(Biesmeijer et al. 2006). Removal of woody vegetation and tillage destroy nesting sites for pollinators (Kremen et al. 2007) and this could cause variations in honeybee colonies and mortalities. Floral diversity provides shelter and forage which forms a good habitat for honeybee colonies (Mujuru and Oeba 2019). Unlike tobacco farming, forestry and citrus farming has positive effects on honeybees' conservation through increased floral resources in fragments of natural ecosystems.

Besides pests, disease and climate change, agrochemicals form another cause of honeybee mortalities. Honeybees forage grounds and the atmosphere around honeybees are in most cases contaminated with chemicals, mostly pesticides (Porrini et al. 2003; Balasha et al. 2019). Tobacco has been singled as a major cash crop in both commercial and communal farming which is intensively grown using pesticides, and these pesticides reach honeybees through

pollen, nectar, air, water or soil. In some of the villages, pesticides such as methamidophos and monocrotophos are still being used despite international conventions banning their use. However, fenvalerate, thiodicarb and acephate have been banned due to their active ingredients and TRB Kutsaga disapproved their use in tobacco from 2018 to 2019 agricultural seasons. The continuous use of environmentally unfriendly pesticides is greatly linked to high honeybee mortalities (Porrini et al. 2003; Balasha et al. 2019).

The relative impact of pesticides on the global decline of pollinators especially honeybees is poorly characterised, however, recent toxicology studies reveal more evidence that some pesticides have clear negative effects on the health of honeybees, both individually and at the colony level (Henry et al. 2010). The study revealed one station in Village 3 recorded a threshold of more than 250 dead
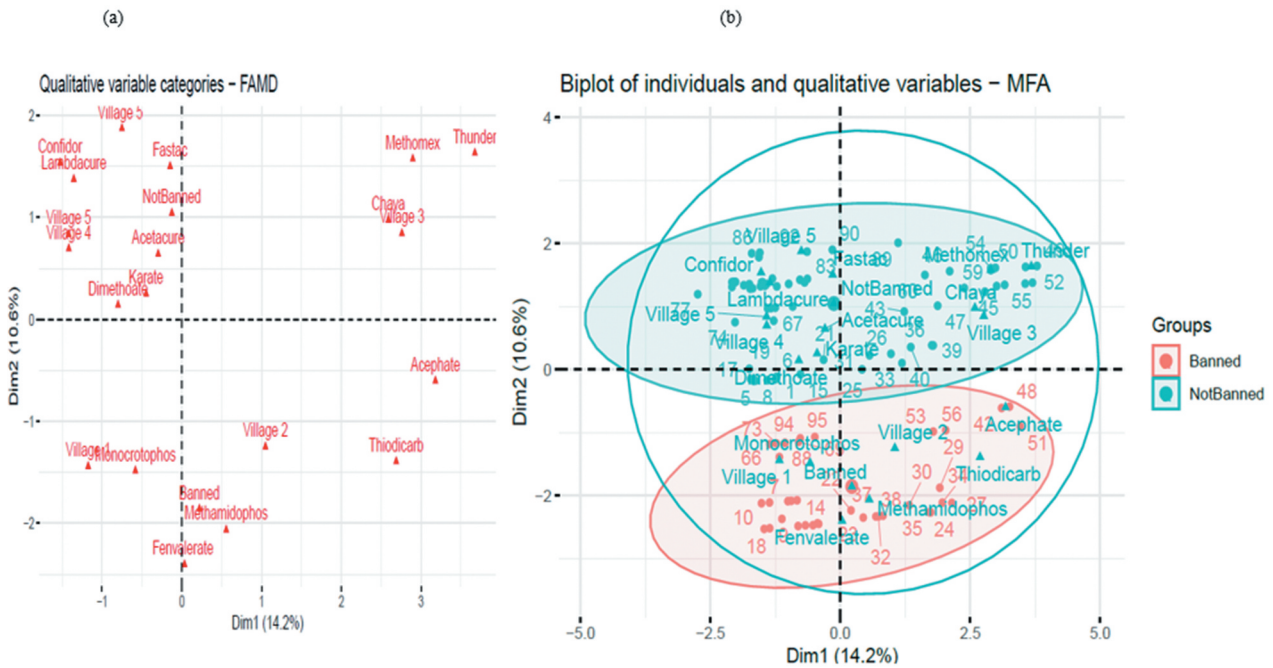

Figure 6. Graphical representation of (a) qualitative variable categories of agrochemicals and villages, and (b) biplot of individuals and qualitative variables for the agrochemicals and villages.

Notes: *Dimethoate- Dimethoate 40 EC, Karate- Karate Zeon 5 CS, Acetacure- Acetacure 20 SP, Chaya- Chaya Extra WG, Fastac- Fastac 10 EC, Thunder-Thunder 145 OD, Lambdacure- Lambdacure 5 EC, Confidor- Confidor 70 WG, Methomex- Methomex 90 SP*

honeybees per week. In Village 3, tobacco was the major cash crop that was grown and involved the intensive use of pesticides that likely induced honeybees' mortality. Pesticides, either at low or high doses can potentially affect honeybees even though they have not been intentionally targeted. There are several reasons why pesticides exposed to honeybees tend to be ubiquitous in agroecosystems. Some pesticides are systemic, where pesticides residues persist in farm soils and dust, air and water, nectar, pollen as well as close weeds in the field after spraying (Girolami et al. 2009; Henry et al. 2010).

The continuous use of environmentally unfriendly agrochemicals in developing countries emanates from the challenges of replacing the banned agrochemicals with the recommended ones (Mudimu et al. 1995; Mando et al. 2019). Most tobacco farmers obtain agro-chemicals from credit schemes cheaply and replacing such chemicals with the recommended ones often increase the cost of production and result in reduced profits (Mudimu et al. 1995; Lalah et al. 2011). Poor information dissemination, limited law enforcement of the existing legislation and limited finances from respective agents result in little information reaching tobacco farmers and compliance to the recommended and wise use of pesticides thus the continued use of harmful agro-chemicals. The banning or deregistering of environmentally unfriendly pesticides can be initiated by the government or departments solely based on ensuring honeybees survival as they play a critical role in plant pollination which is vital in agricultural production and conservation of other floral species which depend on insect pollination (Mando et al. 2019).

The study showed negative effects associated with tobacco production on managed honeybees and such impacts may also have implications for wild honeybees. Trees that were harvested for tobacco curing within a season was far more numerous than the *Eucalyptus* or any other indigenous trees planted as reforestation, and this poses a serious risk of deforestation. The study revealed how anthropogenic activities related to tobacco farming can disrupt managed or wild honeybees' conservation. The current farming practices, i.e. tobacco farming and apiculture were to a greater extent not sustainable considering the continuous use of environmentally unfriendly agrochemicals and high levels of deforestation. A compromise needs to be reached to ensure sustainable agricultural enterprises that support tobacco farming and apiculture. The use of target-specific pesticides and compliance with the regulations reduces the intoxication of non-target key pollinators like honeybees. Intensive reforestation and afforestation programmes on degraded ecosystems with fast-growing indigenous trees, citrus and organically produced crops help to reduce the impact of land

fragmentation which destroys honeybee habitats (Mujuru and Oeba 2019). However, it is important to note that no single factor can be blamed for honeybee mortalities. Mortalities in honeybees can be caused by other factors such as veld fires, pests and diseases, shortage of water and extreme temperatures (Adegbola et al. 1998; Balasha et al. 2019), which point to the need of further studies to determine the interactive effects of these factors on honeybee ecology in savanna ecosystems.

5. Conclusion

The present study revealed high environmental degradation from unsustainable practices such as heavy dependence on firewood to cure tobacco by farmers in NCA. The sole dependence on woody vegetation as source fuel to cure tobacco and clearance of huge pieces of land particularly to cultivate tobacco poses a great threat to honeybees' habitat in the study villages. The present study noted five agrochemicals that were banned by the responsible authorities, i.e. TRB Kutsaga, due to their active ingredients, two of them (i.e. methamidophos and monocrotophos) have been banned under the international convention due to their detrimental effects on the environment. There is a need to (i) promote the use of environmentally friendly and target specific pesticides to protect honeybees from unsustainable agricultural practices, (ii) adopt and support an integrative approach involving all stakeholders to educate farmers on sustainable farming practices and the enforcement of sound environmental practices, (iii) research further on pesticide residues found in pollen grains, nectar, and dead honeybees to fully understand the types and quantities of pesticides with the potential to destroy honeybee colonies in communal areas where tobacco farming is practised.

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