OPEN ACCESS

African Journal of Environmental Science and Technology

July 2022
ISSN 1996-0786
DOI: 10.5897/AJEST
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJEST

African Journal of Environmental Science and Technology (AJEST) provides rapid publication (monthly) of articles in all areas of the subject such as Biocidal activity of selected plant powders, evaluation of biomass gasifier, green energy, Food technology etc. The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles are peer-reviewed

Indexing

The African Journal of Environmental Science and Technology is indexed in:
CAB Abstracts, CABI's Global Health Database, Chemical Abstracts (CAS Source Index), China National Knowledge Infrastructure (CNKI), Dimensions Database, Google Scholar, Matrix of Information for The Analysis of Journals (MIAR), Microsoft Academic

AJEST has an h5-index of 14 on Google Scholar Metrics

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Environmental Science and Technology is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

Article Copyright

Self-Archiving Policy

The African Journal of Environmental Science and Technology is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.

Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Environmental Science and Technology is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.

https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Environmental Science and Technology encourages metadata harvesting of all its content. The journal fully supports and implement the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajest@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJEST

Submit manuscript online http://ms.academicjournals.org

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor,
Kenyatta Avenue, Nairobi, Kenya.

Table of Content

Vol. 16(7), pp. 264-274, July 2022
DOI: 10.5897/AJEST2022.3115
Article Number: 2B5E37369343
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Vegetation dynamics in a fragile ecosystem in relation to land use: The case of the dune cordon of Namaro, southwestern Niger

Issoufou IDE[1*], Amadou ABDOURHAMANE TOURE[1], Halarou NOMA[1], Jean Louis RAJOT[2,3], Bouba HASSANE[1], Adamou Didier TIDJANI[4] and Zibo GARBA[1]

[1]Département de Géologie, Faculté des Sciences et Techniques, Université Abdou Moumouni, BP 10662 Niamey, Niger.
[2]Laboratoire Interuniversitaire des Systèmes Atmosphériques, UMR CNRS 7583, UPEC, UPD, IPSL, Créteil, France.
[3]Institut d'Ecologie et des Sciences de l'Environnement de Paris, UMR IRD 242, UPEC, Sorbonne Université, CNRS, INRA, UPD, Bondy, France.
[4]Département Sciences du sol, Faculté d'Agronomie, Université Abdou Moumouni, BP 10960 Niamey, Niger.

Received 11 April, 2022; Accepted 10 June, 2022

In southeast Niger, the degradation of the environment led to the reactivation of moving dunes that threatens infrastructure, fields, and river with silting. To stabilize the dune cordon of Namaro, which is heavily cultivated and grazed, anti-erosion devices: living hedges and grassland has been developed. The objectives of this work are then to characterize the impact of grassland and hedges on floristic diversity and to highlight the herbaceous species that are most induced a better ecological restoration in this dune environment. The soil cover, floristic diversity, and phytomass yield were determined on the control surfaces (rangelands), as well as on a grassland and living hedges areas. It appeared that the highest biomass yield was recorded in the hedges areas (61.74 kg.ha^{-1} of dry matter). The density of herbaceous in the hedgerow and grassland is increased of at least 2 times of the relative to the rangeland. The inventory of herbaceous families showed that *Corchorus Tridens* Incidentally *Schwenckia americana* marked a decrease in pressure and an improvement in the conditions for the development of vegetation on the dune. *Evolvulus alsinoides* and *Zornia glochidiata* are the most resilient species and marked the adaptation of the vegetation on the heavily grazed dune.

Key words: Namaro, dune cordon, vegetation, land use.

INTRODUCTION

Vegetation plays a vital role for terrestrial environments. It influences carbon and nutrient cycling (Freschet et al., 2018; Leroy, 2019 ; Hain, 2020), crop productivity and soil erosion (Ouatara et al., 2018; Abdourhamane et al., 2019; Moreau et al., 2019). In the case of wind erosion in particular, the height and rate of cover of the soil surface by vegetation plays a crucial role. This is because vegetation protects the soil for a distance equivalent to

*Corresponding author. E-mail: ideissoufou82@gmail.com.

ten times its height (Webb et al., 2020). A soil cover of 2 to 10% by plant residues reduces erosion of Sahelian sandy soils by more than 3 times compared to bare soil (Abdourhamane, 2011; Okothomas, 2019). It has also been shown that a vegetation cover of 40% almost annihilates wind erosion of soils (Fryrear, 1985).

However, vegetation is under pressure and degradation in the Sahel. Indeed, the Sahel is a very sensitive environment to climatic variations (Ozer et al., 2010; Brüning and Piquet, 2018). Rainfall variability has been marked, for example, by recurrent droughts that were particularly severe in the 1970s and 1980s (Descroix et al., 2015; Brüning and Piquet, 2018). One year out of two is rainfall deficient causing a degradation of the biophysical environment (Idrissa et al., 2020). The effect of this climatic pejoration has been accentuated by human pressure (Gemenne et al., 2017; Baldé et al., 2020). The Sahel is the region of the world that has experienced the largest population increase in recent years (Garenne, 2016a, b; Dramani and Mbacké, 2017; Guengant and Delaunay, 2019). The rate of degradation, which is highly variable, is therefore following a trend that is accelerating under the combined effect of periodic droughts and the ever-increasing anthropogenic pressure on resources that have become scarce and fragile (Gbetkom, 2020; Tacon, 2021). The degradation of vegetation is particularly important on fragile surfaces such as dunes. These are heavily grazed and/or cultivated (Idrissa et al., 2020). In Southeast Niger, 26% of the cultivated surfaces have been lost from 1985 to 2005 and have been taken over by mobile dunes due to sand remobilization (Tidjani, 2008). The reactivation of sand dunes surfaces have been observed on ancient cultivated and/or overgrazed area in the east of Niger (Moussa et al., 2014). These pressures have notably led to the reactivation of moving dunes in eastern Niger (Malam et al., 2018; Boureima et al., 2019). The current evolution of these landscapes is therefore characterized by a desertification marked by an advance of the dune fronts of an average of 5.60 ± 2.02 m / year (Tidjani et al., 2017).

However, mobiles dunes cause many environmental and socio-economic problems. They bury crops, pastures, water points and infrastructures (Tidjani et al., 2017). Thus, to protect these assets, mechanical dune fixation has been undertaken in several localities of SE Niger. These fixations consisted of the construction of mechanic hedges. The hedges are maintained for the first three years to allow herbaceous vegetation to grow naturally at the hedge lines.

The dune cordon of Namaro is a particular ecosystem because it is located along the river in a relatively humid environment (525 mm of rain per year). The degradation of its surface by heavy cultivation and grazing led to the reactivation of moving dune which threatens infrastructure, field and river with silting. So to restoration and protect the dune area, anti-erosion devices have been developed since 2006 by the program to fight against silting of the Niger River (PLCE/BN, 2006). It has therefore carried out developments with the aim of developing vegetation on the dune cordon of Namaro. These managements consisted in the construction of grassy surfaces and hedges. However, the ecological role and impact of management has not been evaluated after more than 10 years of implementation. The objective of this work is to characterize the vegetation the Namaro dune in relation to land use. Specifically, it is to: i) characterize the impact of the anti-erosion devices (grassy surfaces and hedges) on the vegetation in terms of coverage, yield and floristic diversity and ii) for the rangelands surfaces most sensitive to wind erosion, to characterize the dynamics of the soil cover by vegetation, which is a fundamental parameter of the dissipation of the energy of the erosive winds.

MATERIALS AND METHODS

Study site

The Namaro dune cordon on which this study is conducted is a sandy accumulation 25 m thick, 2 km wide and 44 km long (PLCE/BN, 2006). The intensification of cultivation and grazing on its surface has increased the winds erosivity and the reactivation of moving dune in some places. Woody vegetation, essentially shrubby, is very sparse and dominated by *Faidherbia albida* and *Annona senegalensis* (PLCE/BN, 2006).

The climate is semi-arid. The average annual rainfall recorded between 1950 and 2007 is 525 mm (Lebel and Ali, 2009). The rainfall recorded in rainy season between June and September is often deficient (one year out of two) and is marked by recurrent droughts. The essentially sandy and nutrient-poor soil supports the main activities of the population. This population, with a density of 43 hbts/km², is 96% rural and its main activities are agriculture and livestock (PLCE/BN, 2006). The study site is located on the dune cordon of Namaro at 30 km northwest of Niamey and 2 km from the village of Bangou Koiré (13°33'34"N-1°54'28") (Figure 1). The measurements were made on four types of land use:

(i) Rangeland of nearly 40 ha: the grazing is free on its surface every season (Photo 1). The presence of the animals is approximately 660 small ruminants and 425 big ruminants per day (Photo 2). The grazing area is dominated by grasses that grow naturally during the rainy season (June to September).
(ii) The anti-erosion devises on the dune surface includes grassy and living hedges areas. These devises cover 26 ha and were built and protected by the Program to Combat Silting of the Niger River in 2006.

The grassed areas aim to protect the surface of the dunes from erosion but also to constitute a stock of food for the livestock (Photo 3). Twelve endogenous herbaceous species were planted on the grassy areas in 2006. In the years following 2006, theses grasses have been seeding in 2007 and 2008. This devices is only partially protected. In fact, the grasses that do grow are not grazed and are only harvested at the end of the dry season (May) and sold in bunches to agropastoralists by the village management committee. The living hedges are made up of Euphorbia lamarckii planted in the form of a square mesh of about 20 m on each side (Photo 4). In the square natural grasses grow up (Photo 4). At this level, there is total defensiveness: no grazing or grass collection is authorized by the management committee.

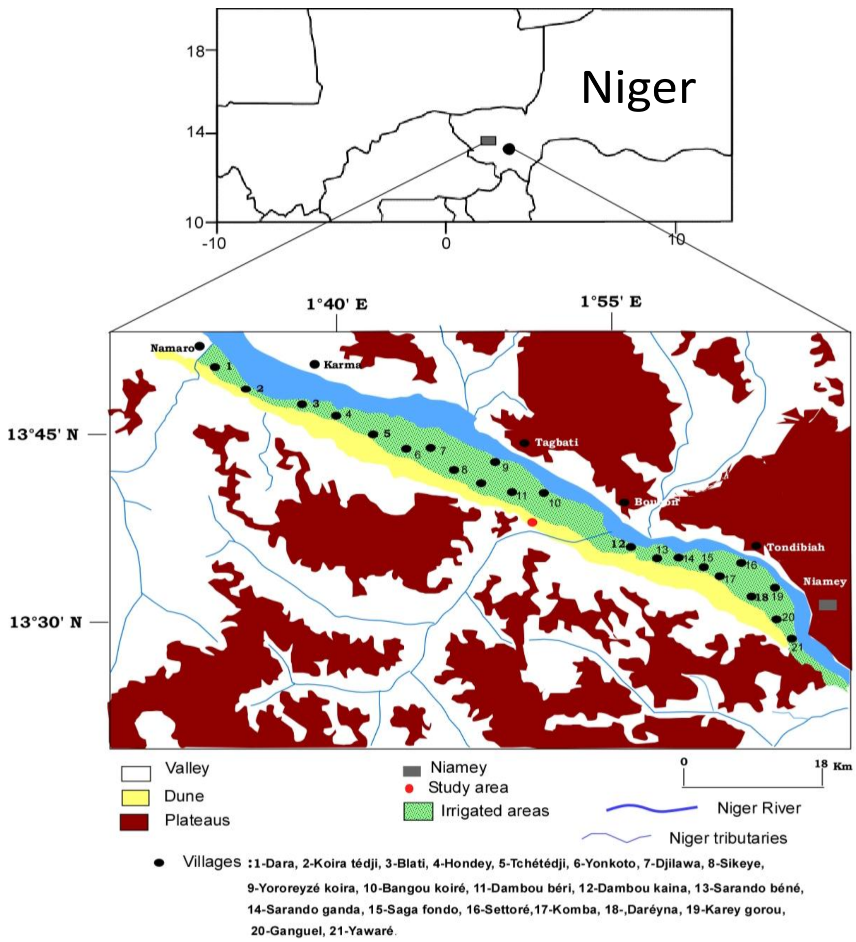


Figure 1. Location and mapping of geomorphological units in the study area. The dune cordon runs along the Niger River for more than 40 km in a NW-SE direction.
Source: Authors

Photo 1. Variation in millet field surface cover: (A) rainy season dominated by millet plants, (B) dry season dominated by crop residues.
Source: Authors

Photo 2. Variation in herbaceous cover of rangeland area (A) rainy season, (B) dry season
Source: Authors

Photo 3. Variation in grass cover of the grassed area (A) rainy season, (B) dry season
Source: Authors

Vegetation sampling

Vegetation cover

This was determined on the rangelands. Two types of cover were determined according to seasons and the appearance of the vegetation. These were the rate of cover by green vegetation during the rainy period (June-October) and a rate of cover by dry residues during the dry period (December-June).

The vegetation cover rate was determined using photographs taken at 1 m from the soil ground. To take of the variability of the plot, twenty points were photographed every week. The photographs were processed on CANEYE © (Diawara et al., 2020) (Photo 5) and ImageJ © (Abdourahamane Touré et al., 2011) (Photo 6) to determine the green vegetation cover rate and the residue cover rate respectively.

Quantification of biomass yield

Biomass yield was quantified on rangeland, grassy area and in the live hedgerow area. Quantification was conducted at the end of the

Photo 4. Aerial view of Euphorbia lamarckii clays on the dune cordon (Google Earth image). The white circles indicate the positions of the biomass measurement points.
Source: Authors

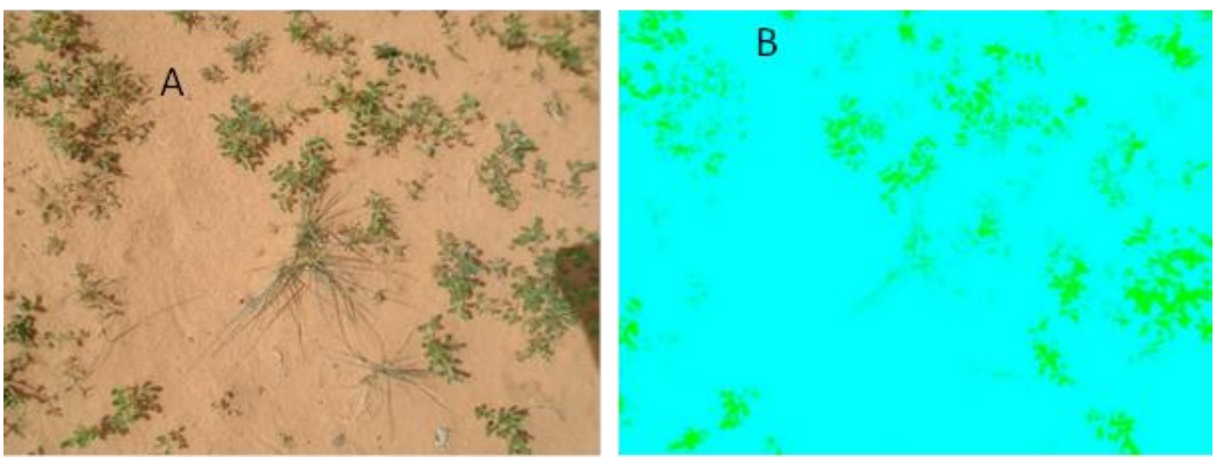


Photo 5. (A) photograph of the grass layer in the rainy season taken at 1 m from the surface of the rangeland; (B) cover rate (6.54%) determined by photo processing in CANEYE.
Source: Authors

rainy season (October), when the grasses have reached maturity.

A 1 m×1 m quadrant (Photo 6) was used to quantify biomass yield. Sampling was conducted along two orthogonal transects on the open rangeland and grassy area. Each transect had ten sampling points spaced 10 m apart. The same quadrant was used in the hedgerow area where two types of transects were delimited: the first is located two meters and the second 10 m from the hedgerow line. In the hedgerow area, eight transects were delineated. Each transect had 5 sampling points spaced 5m apart (Photo 4).

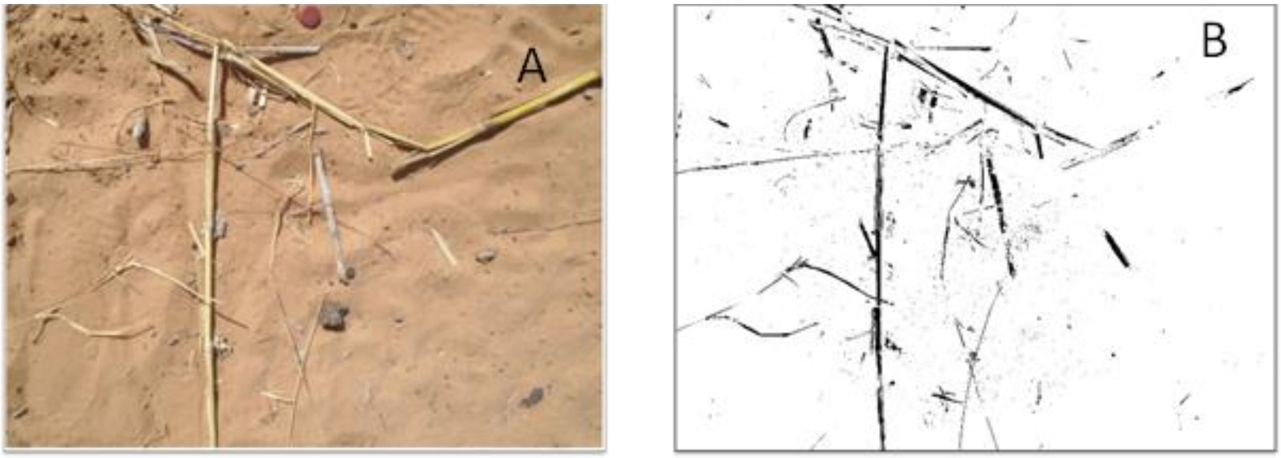
Grasses were collared on the rangeland, grassy area and hedgerow areas. The collected grasses were then dried at room temperature for 21 days and the dry residue yields were calculated (Equation 1). It should be noted, however, that prior to collection of the grasses, the inner surface of the quadrant was photographed and then the vegetation cover was determined under CAN EYE.

$$RS = M/S \quad (1)$$

Where RS: dry residue yield; M: average of dry herbaceous masses collected in the transect; S: area of the (1 m × 1 m).

Inventory of herbaceous species on uses

It was carried out concomitantly to the measurements of the



Photos 6. (A) Photograph of crop residue taken at 1 m from the soil surface in the field; (B) Crop coverage (3.152%) determined by photo processing in ImageJ CANEYE.
Source: Authors

biomass on the course, and the area of the living hedges. It was thus determined in 20 point quadrants of 1 m² on the rangeland as well as on the grassy area and on 40 point quadrants in the area of the living hedges. Herbaceous species were identified and their numbers and relative frequencies (Pe) were calculated in each soil use (Equation 2).

$$Pe = \Sigma ni/N \quad (2)$$

Where Σni= number of the individuals of specie i on the land use; N= number of the individuals of all species on the land use.

For each species, a mean density (number of the individuals of specie i per m² on the land use) has been calculated (Equation 3). A statistical test (ANOVA, with a threshold of 5%) was performed to compare the mean densities calculated for each land use.

$$de = \Sigma ni/S \quad (3)$$

Where de = a mean density of specie i on the land use; Σni= number of the individuals of specie i on the land use; S = surface of the measurement which is 20 m² on the rangeland and grassy area and 40 m² in the hedges.

RESULTS AND DISCUSSION

Dynamics of soil cover by vegetation on the rangeland

Vegetation cover showed a unimodal annual evolution marked by an expansion of grasses during the rainy season (July-October) (Figure 2). The greatest expansion of herbaceous occurs in July after the monsoon jump and the regularity of rainfall (Figure 2). In the Sahel, it has been shown that the development of herbaceous cover is particularly sensitive to rainfall distribution (Hiernaux et al., 2010). On the rangeland, grasses reached their maximum cover of 7.76% and 1.86% respectively in the middle and end of the rainy season in 2019 and 2020 (Figure 2). Green herbaceous cover showed inter-annual variability. Indeed, it is recognized that in the Sahel, herbaceous cover can vary on the same site from one year to another depending on climatic conditions (Hiernaux and Le Houérou, 2013): during the 2019 rainy season, cover was 4 times greater than in 2020 (Figure 2). The lower herbaceous cover in the 2020 rainy season than in 2019 is opposite to that of recorded rainfall (Figure 2). This would most likely be related to greater pastoral pressure in 2020. Rangeland surface cover was less dense than on the Kilakina (East Niger) and Gourma Malien rangelands where it exceeded 30% (Mougin et al., 2014; Abdourhamane et al., 2019; Diawara et al., 2020). During the dry season, the cover for herbaceous residues decreased steadily. It decreased from 5% in November to less than 1% in June in 2019 and from 1.5% in December to less than 1% in June 2020 (Figure 2). The decline in residue cover is particularly rapid during the first few months after the rainy season, as it has been observed on both the Niger and Mali rangelands (Hiernaux and Le Houérou, 2013; Abdourhamane et al., 2019). The decrease in residue cover is therefore classic on sahelian rangelands. It is mainly explained by pastoral pressure and secondarily by the burial of residues by wind deflation.

The interannual variability of residue cover is closely linked to the rainy season. Indeed, the rate of residue cover in the dry season is related to the rate of cover developed during the previous rainy season. The higher growth of the rainy season in 2019 induced a higher residue cover in the following dry season (Figure 2).

Variation in biomass yield by land use

Biomass yield varied greatly by soil use. The biomass yield of the Hedgerow was 6.3 and 2.6 times higher than those of the rangeland and the grassland area respectively. Plant production in the Hedgerow can be

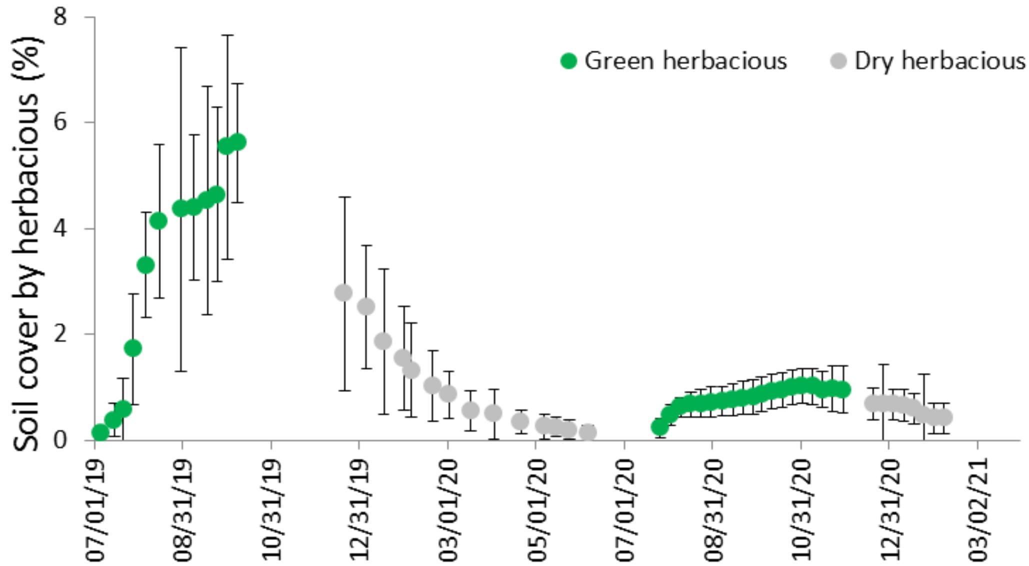


Figure 2. Evolution of mean soil cover by the herbaceous on the rangeland (the vertical lines indicate the standard deviation). The cover increases and reaches its maximum value in rainy season then decreases in dry season to reach less than 1%.
Source: Authors

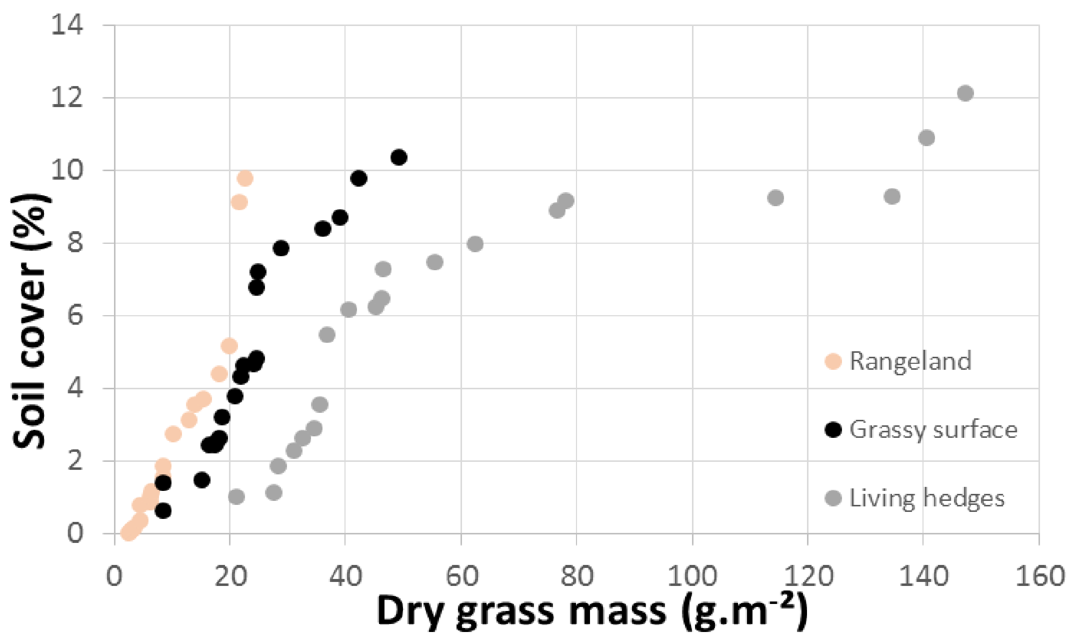


Figure 3. Relationship between the dry mass of herbaceous plants and their cover rate on the different land uses present on the dune cordon. The green vegetation of the range is respectively 2 and 4 times more covering than those of the grassland and hedges.
Source: Authors

therefore a major source of animal feed and fodder stock in the dry season. On the rangeland, the biomass measured at the end of the rainy season was 9.79 $kg.ha^{-1}$: the yield on this land use would probably have been higher taking into account the removal due to grazing. Figure 3 has allowed us to discriminate between the different land uses. It shows a linear increase in the cover of the rangeland and the grassed area as a function of the mass of the herbaceous plants. In the living hedges, a linear increase in cover is also apparent for low herbaceous masses (less than 80 g.m⁻²). For larger masses, the efficiency of ground cover by grasses decreased in the live hedges (Figure 3). Comparing the various land use, it appears that the rangeland plants are 2 and at least 4 times more covering than those of the grassed areas and the hedgerows (Figure 3).

Variation of herbaceous families and species according to land use

Twenty-four species divided into 17 families were inventoried on the dune cordon under an average rainfall of (525 mm). This diversity is lower than that observed on the Toukounous rangelands (West Niger) and close to Sayam rangelands (East Niger), where 75 and 27 species were counted respectively (Idrissa et al., 2020). Annual rainfall in Toukounous and Sayam is at most 350 mm over the last 60 years. Rainfall in these areas is less than at Bangou Koiré where floristic diversity is relatively low. The difference in floristic diversity could therefore be related to the nature of the soils. Indeed, the rangelands in Bangou Koiré are located at the top of the dune while in Toukounous, for example, they are distributed between lowlands and plains (Saidou and Ambouta, 2013).

Herbaceous plants on all land uses (rangelands, grassy area, hedgerows) were marked by differences in the number of families and species (Table 1). In fact, in the area of living hedges, 15 families were listed that is, 2 and 4 more than in the grassy area and rangelands respectively (Table 1).

On the rangeland, seventeen species inventoried with a total 493 individuals counted. The most diversified families: Fabaceae and Poaceae with 3 species; Convolvulaceae and Papilionaceae with 2 species (Table 1). All these species are natural. Four of the species (*Evolvulus alsinoides, Zornia glochidiata*, *Sida cordifolia* and *Cenchrus biflorus)* have a density greater more than one individual per m². The cumulated relative frequency of these species represents more than 78% on the rangeland.

On the grassed surface, nineteen species were recorded with a total of 1086 individuals counted. The most diversified families on the grassed areas are, Fabaceae, Papilionaceae, and Convolvulaceae, with 2 species and Poaceae with 3 species (Table 1). Twelve endogenous species were sown between 2006 and 2008, but they did not develop harmoniously. Indeed, only four species have an average density higher than one individual per square meter. These are *Pergularia tomentosa, Z. glochidiata, Alysicarpus ovalifolius* and *Eragrotis tremula* (Table 1). These species represent more than 90% of the relative frequency of species inventoried on the grassed areas.

Indeed, nineteen species divided with a total 2457 individuals were counted on the living hedges. The most diversified families are: Malvaceae, Poaceae, Papilionaceae and Rubiaceae which count two species each (Table 1). It should be remembered that all the species grew naturally in the area of the hedgerows. Nine of these species have an average density greater than one individual per m² (Table 1). These are particularly *Z. glochidiata, A. ovalifolius, E. tremula* and *Mitraearpus villosus* which has a density of more than 10 individuals per square meter. These four species represent more than 75% of the relative frequency of species inventoried on the living hedges (Table 1). The role of the devices in ecological restoration is thus apparent, with an increase in the number of families and species in the hedgerow and grassy areas relative to the grazed range. Thus, the number of grasses was 61, 54 and 25 individuals per m² respectively in the hedgerow area, the grassy areas and the rangelands. The density of grasses that are close on the landscapes (grassy areas and hedges) are more than twice that of the rangelands. The role of managed areas in the diversity and the floristic richness quantitatively and qualitatively was also observed in the pastoral spaces of the semiarid area (Benaradj and Boucherit, 2014; Idrissa et al., 2020).

The herbaceous families inventoried on the rangeland with high grazing pressure, were observed on all the other two land uses (grassy area and living hedges) (Table 1). These families, mainly dominated by Poaceae, Malvaceae, Papillonaceae and Convolvulaceae*,* appear to be the resilient forbs on the dune. The most resilient species are *E. alsinoides* and *Z. glochidiata* which have a relative frequency of 33.47 and 29.25% respectively in the rangeland. *Z. glochidiata*, however, remains a major species at least 20% of relative frequency on each of the land uses (Table 1). This species belongs to the Malvaceae family which is recognized for its resistance to the various environmental disturbances recorded in the Sahel (Saidou and Ambouta, 2013; Kaou et al., 2017). Malvaceae have however been identified as markers of environmental restoration in equatorial Africa (Kaboneka et al., 2020). Convolvulaceae particularly *E. alsinoides* was more prevalent on rangelands (8.25 individuals per m²) in contrast to grasslands (0.3 individuals per m²) and hedgerows (0 individual per m²) (Table 1). The increase in the proportion of *E. alsinoides* on the rangeland marks the adaptation of the vegetation to grazing pressure. *Corchorus Tridens* (Tiliaceae) inventoried only on the restored areas (grassed area and hedgerow area) appears to be marker of a decrease in pressure and an improvement in the conditions for the development of vegetation on the dune cordon of Namaro. On the soils of Mainé Sorao (East Niger), Tiliaceae were markers of average environmental fertility (Kaou et al., 2017). Incidentally, *Schwenckia americana* (Solanaceae) inventoried on only on the grassland could be secondary markers of a decrease in pressure and an improvement in the conditions for the development of vegetation.

Table 1. Number and mean density of species recorded on the different land uses.

Families	Species	Rangeland				Grassland				Hegdes			
		Number	Mean density (individuals/m²)	t	Standard deviation	Number	Mean density (individuals/m²)	t	Standard deviation	Number	Mean density (individuals/m²)	t	Standard deviation
Convolvulaceae	*Merremia pinnata**	7	0.35	a	0.53	6	0.3	a	0.42	32	0.8	a	1.12
	Evolvulus alsinoides	165	8.25	a	5.78	0	0.05	b	0.10	0	0	b	0.00
Commelinaceae	*Commelina forskalae*	3	0.15	a	0.27	0	0	a	0	6	0.15	a	0.29
Solanaceae	*Schwenckia americana*	0	0	a	0	13	0.65	b	1.04	0	0	a	0.00
Cucurbitaceae	*Maerua crassifolia*	0	0	a	0	0	0	a	0	5	0.125	a	0.23
Tiliaceae	*Corchorus Tridens**	0	0	a	0	17	0.85	b	1.275	2	0.05	b	0.09
Scruphulariaceae	*Striga hermontheca*	0	0	a	0	0	0	a	0	6	0.15	a	0.27
Rubiaceae	*Spermacoce ruelliae*	0	0	a	0	6	0.3	a	0.51	18	0.45	a	0.79
	Mitraearpus villosus	10	0.5	a	0.55	6	0.3	a	0.48	411	10.275	b	10.64
Amaryllidaceae	*Zephyranthes candida*	2	0.1	a	0.18	9	0.45	a	0.72	0	0	b	0.00
Poaceaes	*Eragrotis tremula**	11	0.55	a	0.66	149	7.45	a	4.875	488	12.2	b	13.23
	*Aristida pallida**	6	0.3	a	0.45	12	0.6	a	0.78	0	0	b	0.00
	*Cenchrus biflorus**	51	2.55	a	2.015	2	0.1	a	0.18	82	2.05	a	3.59
Pedalilaceaee	*Ceratotheca Sesamoides*	2	0.1	a	0.18	1	0.05	a	0.095	80	2	a	3.10
Papilionaceae	*Tephrosia lupiniifolia**	13	0.65	a	0.65	1	0.05	a	0.095	28	0.7	a	1.02
	*Alysicarpus ovalifolius**	17	0.85	a	0.935	48	2.4	a.b	2.18	472	11.8	b	15.98
Fabaceae	*Trephosia linearis**	8	0.4	a	0.6	13	0.65	a.b	0.91	0	0	a.c	0.00
	Sesbania sericea	0	0	a	0	0	0	a	0	21	0.525	a	0.92
	*Zornia glochidiata**	144	7.2	a	8.6	627	31.35	b	18.12	510	12.75	a	15.94
Apocynaceae	*Pergularia tomentosa**	16	0.8	a	0.8	161	8.05	a	6.565	62	1.55	a	1.55
Cyperaceae	*Cyperus olopecuroides**	10	0.5	a	0.65	11	0.55	a	0.715	10	0.25	a	0.48
Euphorbiaceae	*Euphorbia aegyptiaca**	2	0.1	a	0.19	2	0.1	a	0.18	142	3.55	a	3.07
Malvaceae	*Sida cordifolia*	26	1.3	a	2.01	1	0.05	b	0.095	52	1.3	b	1.74
Sterculiaceae	*Walteria indica*	0	0	a	0	0	0	a	0	30	0.75	a	1.43

An Anova test, t, (5% threshold) was applied to compare the mean density of each specie (mean densities that are not significantly different for the same specie according to land use have the same letter; if the letter is different, the difference in mean densities is significant). * indicates the species sown between 2006 and 2008 on the grassed areas.
Source: Authors

Indeed, the Solanaceae family has been highlighted as markers of ecological restoration (Kaboneka et al., 2020).

Conclusion

The herbaceous on the rangeland were 2 and 4 times more covering than those in the grassy area and hedgerows. Soil cover by vegetation showed a unimodal evolution. The maximum cover by the more important green vegetation was 7.76% on the rangeland. These rates were decisive for the cover by residues, which decreased to less than 2% in the middle of the dry season, from January-February. Biomass yields also varied according to land use. At the end of the rainy season, the vegetation yield was 61.74 $kg.ha^{-1}$ on the hedgerows, that is, 6.3 and 2.6 times that of the rangeland and grassed area respectively. On the rangeland, with daily grazing on its surface, the biomass measured at the end of the rainy season was 9.79 $kg.ha^{-1}$.

The herbaceous diversity is low to moderate. Twenty-four species in 17 families were identified. The role of the devices in ecological restoration appears with an increase of the species in the hedgerow and grassy areas relative to the grazed range: it's reached 61, 54 and 25 individuals per m² respectively in the hedgerow area, the grassy areas and the rangelands. The most resilient herbaceous species which show the adaptation of the vegetation on the heavily grazed dune are *E. alsinoides* and *Z. glochidiata.* While *C. Tridens* Incidentally, *S. americana* inventoried on the restored areas (grassed area and hedgerow area) appears to be marker of a decrease in pressure and an improvement in the conditions for the development of vegetation on the dune cordon of Namaro.

It should be noted that the results of this study will be used to better restore the ecology of degraded dune lands. Indeed, the use of species that are palatable to animals and highly resilient, such as *E. alsinoides* and *Z. glochidiata*, could lead to a better result. It would be interesting to verify the effectiveness of these two species in stabilizing dunes in the pastoral zone of Niger (less than 300 mm of rainfall per year) where wind silting and desertification processes are more pronounced.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENT

The authors are grateful to UMR IEES-Paris (IRD) and SFR RACINES for their supports.

REFERENCES

Abdourhamane TA (2011). Erosion en milieu sableux cultivé au Niger : Dynamique actuelle et récente en liaison avec la pression anthropique et les changements climatiques. PhD thesis, Université de Bourgogne, France 224 p.

Abdourhamane TA, Tidjiane AD, Rajot IJ, Marticorena B, Bergametti G (2019). Dynamics of wind erosion and impact of végétation cover and land use in the Sahel: A case study on sandy dunes in southeastern Niger. Catena 177(2019):272-286.

Baldé O, Ndiaye KB, Faye B, Pascal S, Ba A, Ndaye P, Coly I (2020). Elevage extensif et restriction des parcours à Tankanto escale : effets de la pression foncière ou occupation et utilisation anarchique de l'espace. ISSN: 2489-2068. 5(2).

Benaradj A, Boucherit H (2014). Integrated management of pastoral ressources in the area of Naama (Algeria). Revue algérienne de développement économique N°01/Dec 2014.

Boureima S, Ibrahim M, Lawali S (2019). Les pratiques paysannes de régénération naturelle assistée des arbustes favorisent le développement des mycorhiziens arbusculaires. Agronomie Africaine 31(2):147-158.

Brüning L, Piquet E (2018). Changements environnementaux et migration en Afrique de l'Ouest. Une revue des études de cas, Belgeo mis en ligne le 29 novembre 2018. URL: http://journals.openedition.org/belgeo/28836

Descroix L, Diongue Niang A, Panthou G, Bodian A, Sané T, Dacosta H, Malam Abdou M, Vandervaere JP, Quantin G (2015). Evolution récente de la mousson en Afrique de l'Ouest à travers deux fenêtres (Sénégambie et le bassin du Niger Moyen). Climatologie 12:25-43.

Diawara MO, Hiernaux P, Sissoko S, Mougin E, Ba A, Soumaguel N, Diakité SH (2020). Sensibilité de la production herbacée aux aléas de la distribution des pluies au Sahel (Agoufou, Mali) : une approche par la modélisation. International Journal of Biological and Chemical Sciences 14(4):1341-1353.

Dramani L, Mbacké C (2017). Africa's Demographic Dividend-An Elusive Window of Opportunity? International population conference. Cape Town, South Africa, 2017.

Freschet TG, Cyrille V, Roumet C (2018). Interaction entre sol et la végétation: structure des communautés de plantes et fonctionnement du sol. Les sols au cœur de la zone critique 6:83-99.

Fryrear DW (1985). Determining soil aggregate stability with a rapid rotary sieve. Journal of soil and water conservation 40:231-238.

Garenne M (2016a). Demographic dividend in Africa: macro-and microeconomics effects. N-IUSSP.

Garenne M (2016b). La pression de la population dans les pays Sahéliens Francophones : Analyse des estimations et projection des populations 1950-2100. Ferdi 30 p.

Gbetkom GP (2020). Etudes des dynamiques spatiales d'évolution de l'occupation et de l'utilisation des sols dans la fenêtre lacustre camerounaise du lac Tchad et son arrière- pays à partir des grandes sécheresses sahéliennes de 1970. Environnement et Société. Aix Marseille University, Français.

Gemenne F, Blocher JM, De Longueville F, Vigil Diaz TS, Zickgraf C, Gharbaoui D, Ozer P (2017). Changement climatique, catastrophes naturelles et Déplacements de populations en Afrique de l'Ouest. Revue Internationale de Géologie, de Géographie et d'écologie Tropicales 41(3).

Guengant PG, Delaunay D (2019). Le dividende démographique en Afrique Subsaharienne. ISSN 2554-3687. 118 p

Hain R (2020). Indice de la végétation sur les ambiances microclimatique urbaine: cas des jardins publics à Jijel. Thèse, Université de Jijel, Algérie 259 p.

Hiernaux P, Le Houérou HN (2013). Les parcours du Sahel. Sècheresse 17(1-2):51-71.

Hiernaux P, Mougin E, Diarra L, Soumaguel N, Lavenu F, Tracol Y, Diawara M (2010). Rangeland response to rainfall and grazing pressure over two decades: herbaceous growth pattern, production and species composition in the Gourma, Mali. Journal of Hydrology 375(1-2):114-127.

Idrissa I, Morou B, Abdoulaye D, Saley K, Ali M (2020). Caractérisation des pâturages herbacés sahéliens à accès limité : cas du centre Secondaire de Multiplication de Bétail de Sayam (Diffa). Journal of Applied Biosciences 156:16087-16094.

Kaboneka S, Ndayishimiye J, Hakizimana S, Ndagijimana E (2020). Analyse des phyto-indicateurs de la fertilité des sols en communes

Mabanda et Vugizo (Burundi). Revue de l'Université de Burundi pp. 01-12.
Kaou k, Ousmane L, Guimbo I, Saley K (2017). Diversité floristique et structure de la végétation dans la zone dunaire du sud-Est du Niger : Cas de Mainé soroa. Journal of applied Biosciences 120:12053-12066.
Leroy F (2017). Effet des changements de végétation dans les tourbières à Sphaignes sur le Cycle du carbone. Thèse, Université d'Orléan 185 p.
Malam AM, Ambouta KJ, Bielders CL, Tidjiani DA (2018). Caractérisation de la végétation des dunes dégradées du sud-est du Niger. EWASH£ Ti Journal 2(4):83-94.
Moreau D, Pointurier O, Bernard N, Villerd J, Colbach N (2019). Dans quels systèmes de culture les adventices résiduels peuvent elle réduire la lixiviation du nitrate et l'érosion des sols. Séminaire final du projet de recherche ANR CoSAC- Gestion des adventices dans un contexte de changement 12 p.
Mougin E, Diawara M, Hiernaux P, Soumaguel H, Berg A (2014). Estimation of LAI, FAPAR and Fcover of Sahel rangelands (Gourma, Mali). Agricultural and Forest Meterology pp. 198-199.
Moussa IA, Garba Z, Somé YS, Abdourhamane TA, Yacouba H (2014). Erosion Response to Landscape Unit Changes in Eastern Niger: The Case of Bagara and Issari. British Journal of Applied Science and Technology 4(21):2970-2984.
Okothomas E (2019). Pratiques culturales et sensibilité des sols à l'érosion dans quelques périmètres maraichers de la banlieue de Lubumbashi. Thèse de doctorat, Université de Liège, Belgique 184 p.
Ouatara B, Coulibaly K, Edmond k, Doumbia S, Ouedraogo S (2018). Effet du système de culture sous couverture Végétal (SCV) sur les flux hydriques d'un sol férigineux du Burkina Faso. International Journal of Biological and Chemical Sciences 12(4):1770-1783.
Ozer P, HountondjI Y, Niang AJ, Karimoune S, Laminou Manzo O, Salmon M (2010). Désertification au Sahel: historique et perspectives. Bulletin de la Société Géographique de Liège 54:69-84.
PLCE/BN (2006). Récupération des terres dégradées et fixation des dunes. Version définitive, Ministère de l'environnement et de lutte contre la désertification 92 p.
Saidou S, Ambouta JM (2013). Part contributive de la densité démographique au reverdissement de certaines zones fortement anthropisées du Sahel: cas des Communes d'Aguié et d'Ibohamane au Niger. International Journal of Biological and Chemical Sciences 14(3):816-834.
Tacon F (2021). Déforestation : Essai sur un problème planétaire. Quae pp. 2775-987.
Tidjani AD (2008). Erosion éolienne dans le Damagaram Est (Sud-Est du Niger) : paramétrisation, quantification et moyens de lutte. Thèse de doctorat, Faculté d'ingénierie biologique, agronomique et environnementale, Université catholique de Louvain 193 p.
Tidjani AD, Touré A, Rajot JL, Marticorena B, Bielders CL, Bouet C (2017). Flux éolien et dynamique des fronts dunaires dans le Manga (Sud-Est du Niger). Revue Ivoirienne des Sciences et Technologie 28:323-332
Webb NP, McCord SE, Edwards LB, Herrick EJ, Kachergis E, Okin SG, Zee, VW (2020). Vegetation canopy gap size and height: critical indicators for wind erosion monitoring and management. Rangeland Ecology and Management 76:72-82.

Vol. 16(7), pp. 275-285, July 2022
DOI: 10.5897/AJEST2022.3111
Article Number: 861413669423
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Environmental implications of pesticide use and application practice on beekeeping: Evidence from Gudeya Bila Woreda of East Wollega Zone in Oromia Regional State, Ethiopia

Abaya Alemu Gadissa[1]*, Shimeles Damene[2] and Berhan Mellese Teklu[1]

[1]Ethiopian Agricultural Authority (EAA), Addis Ababa, Ethiopia.
[2]Centre for Environment and Development Studies, College of Development Studies, Addis Ababa University, Ababa, Ethiopia.

Received 23 March, 2022; Accepted 14 June, 2022

The existence of honeybees within the ecosystem is crucial in worldwide agricultural production. Exposure of these insects to residues of many contaminants or poisonous materials like plant protection products (pesticides) causes death or reduces their activity. This study aims to assess the status of pesticide application, its use and possible impacts on bee communities in East Wollega Zone of Oromia Regional State, Ethiopia. A simple structure questionnaire and key informant interviews were conducted to generate qualitative and quantitative data. A pre-developed model called Pesticide Risks In the Tropics for Man, Environment and Trade (PRIMET) was used to determine risks to bees when beehives are in the in-crop and off-crop situations. Results of the analysis indicated that pesticides, particularly carbaryl, malathion, diazinon, fipronil, chlorpyrifos and profonefos are highly risky to bees when used in the in-crop situations (ETRs 3254-120000); while they are possibly risky when used in the off-crop scenario (ETRs 91-335). The result also revealed that farmers are not aware of how to protect bees while applying pesticides. Developing proper risk communication strategies (selecting time of application when honey bees are inactive, covering hives during application, notifying beekeepers before pesticide application) and awareness creation are recommended to avert damage.

Key words: Pesticides, risk assessment, PRIMET, bees, Ethiopia.

INTRODUCTION

Pesticide use definitely helps to improve crop productivity and quality if the right type is used at the right time with the correct dose (Khan et al., 2010). Farmers in Africa have long adapted to climatic and other risks by diversifying their farming activities (Ebi et al., 2011).

The uncontrolled use of pesticides has become one in

*Corresponding author. E-mail: abayaalemu6@gmail.com.

every of the foremost alarming challenges when pursuing sustainable development. Although pesticides are directly applied in soils and plants, just few amount of pesticide sprayed is delivered to the intended target. An accidental release of pesticides due to leaking pipes, spills, waste dumps, underground storage tanks, and groundwater may lead to their persistence within the environment for a protracted time (due to long half-lives). For proper management of pesticides, one should accurately assess the status of their contamination in soil, water, and air (Knapton et al., 2006). Multiclass environmental endocrine disruptor compounds (EDCs), like organochlorine pesticides (OCPs), phthalate esters (PAEs), and polybrominated diphenyl ethers (PBDEs) may coexist in soils and accumulate in crops and human bodies through food chains, posing risks to human health and thus the ecosystem (Net et al., 2015).

Insecticides may kill not only the target species but also other invertebrates on which birds rely on for their food. Additionally, herbicides are designed to manage weed species which also kill many other plant species in fields, including the essentially beneficial species, which give both shelter and food for the members of wildlife. Amphibians are now considered as the foremost threatened and rapidly decreasing species on earth (Brühl et al., 2013).

In Ethiopia, due to the intensification of agricultural activities, inputs like pesticides and fertilizers use are increasing at an alarming rate (Mengistie 2016; Amera and Abate, 2008). The influence of pesticides on the environment consists of the harmful and toxic effects of pesticides to non-target plants and animals. Residues of pesticides may contaminate all the environmental compartments including soil, air and surface or ground water (Gupta et al., 2003; Konstantinou et al., 2006). Thus, the global use of pesticides may have contributed to environmental degradation and depletion of biodiversity negatively impacting the wellbeing of the global flora and fauna (Al-Shaalan et al., 2019; Naik and Wanganeo, 2014; Zhang et al., 2011; Ali and Jain, 1998).

Among the widely impacted non-target animals by pesticide application, bees are the main concern. There are 20,000 species of bees on earth, pollinating 90% of the 107 main crops in the world. Bee numbers have declined dramatically in recent years (Sheridan, 2017). It is estimated that 75% of the world's honeybees have been found to have traces of bee-damaging insecticides, particularly to neonicotinoids, such as *acetamiprid, clothianidin, imidacloprid, thiacloprid*, and *thiamethoxam* (Sheridan, 2017).

Ethiopia is known for its immense variety of agro-climate and biodiversity conditions that favored the life of diversified honeybee flora and large numbers of colonies of honeybees (Nuru, 2007). Thus, beekeeping may be a long-standing tradition in Ethiopia's rural communities (Yirga and Teferi, 2010). Being an export commodity, it has significant contribution for household wealth and poverty reduction as well as the economy of the country. Central Statistical Agency (2011) report shows that Ethiopia is among the four largest beeswax producing countries. For example, the honey export in 2010/2011 production year was estimated to be 620,101 kg from which the country on average generated 420 million Ethiopian Birr on annual basis from the sale of honey. It is estimated that the overall honeybee colonies population in the country is estimated to be10 million, of which 7.5 million are tamed, while the remaining are from wild colonies found in forests (Kenesa, 2018).

However, with the introduction of pesticides in Ethiopia, the poisoning effect of the agro-chemical on honeybees has been increasing over time, where some beekeepers have even lost all their colonies (Kerealem et al., 2009). In connection to this, Melaku et al. (2008) attributed colonial death and absconding with insecticides and herbicides. Chauzat et al. (2006) also showed that improper use of insecticides results in the demise of honeybee. Study conducted by Fikadu (2020) attributed the declining of honeybees’ pollinators with unwise use and practices of pesticides to lack of knowledge of pest, and predators’ management causes the misuse of pesticide.

Pesticides are harmful compounds with a common mode of action, which means that they are primarily engineered to regulate a target group of species by interacting with certain biochemical pathways. Pesticide effect on species can be categorized based on the lethal dose (LD50) values which determine the dose that kills 50% of the exposed animal after a given time of exposure. The sub-lethal effect induced by the chemical to the exposed organisms can also cause other irregularities in their behavioural and physiological activities including stress paralysis or irregular habits without killing them like exposure to neurotoxic insecticides. This effect works for bees as it does for any other organism (Chakrabarti et al., 2015; Zaluski et al., 2015; De Grandi-Hoffman et al., 2013).

Various tools are used to determine risks of agrochemicals to non-target organisms. Among them is an already developed pesticide risk assessment tool for an Ethiopian situation known as Pesticide Risks In the Tropics for Man, Environment and Trade (PRIMET). This tool was developed in collaboration with Wageningen University of the Netherlands, considering specific scenarios in Ethiopia and can be taken as a pioneer in Africa. It can estimate risks of pesticides currently registered or to be registered in Ethiopia for non-target organisms including bees. The software calculates the Exposure Toxicity Ratio (ETR) for each chemical pesticide for both off-crop and in-crop scenarios (Wipfler et al., 2014).

The impact of harmful pesticides on bees and assessment of risks need to be studied in Ethiopia. Even

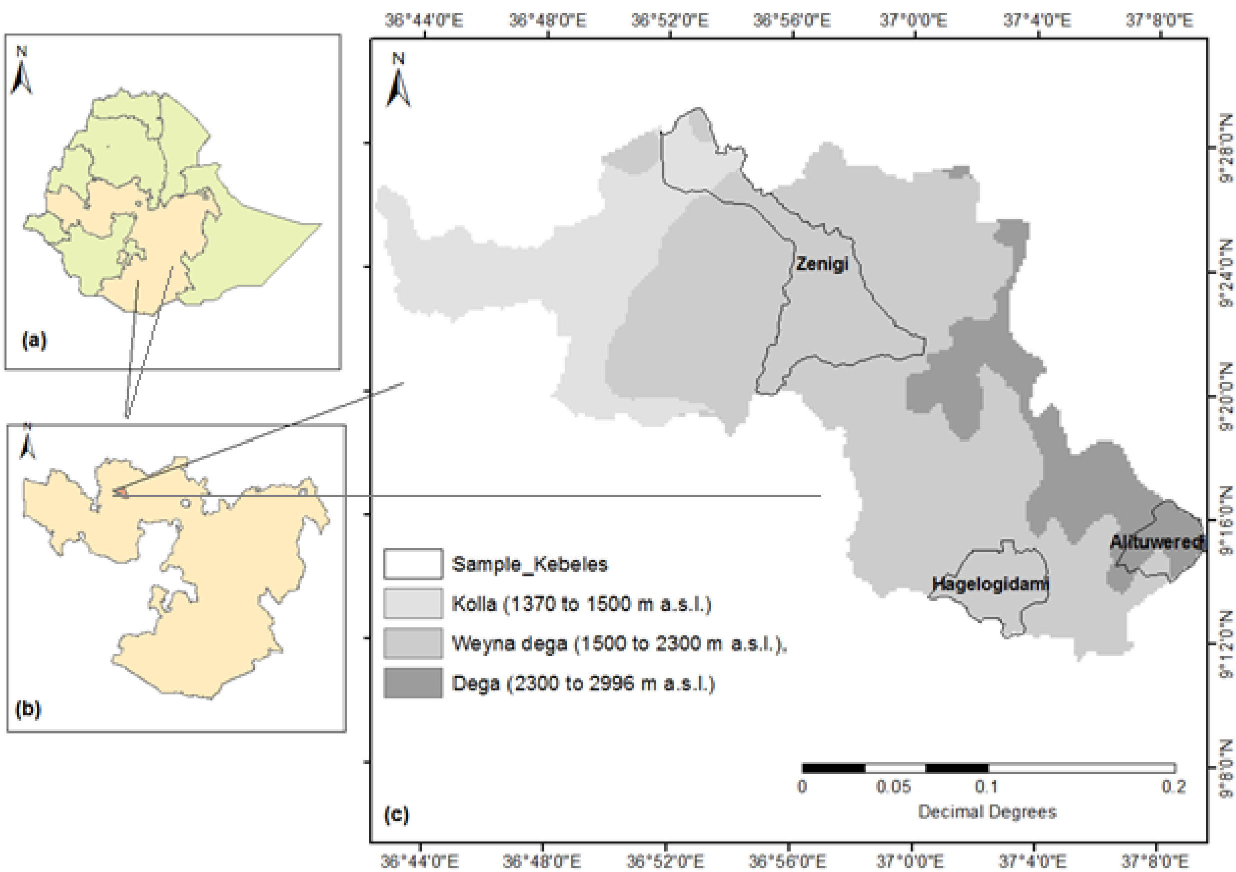


Figure 1. Location and agro-ecological map of Gudeya Bila: (a) Oromia region in Ethiopia, (b) Gudeya Bila wereda in Oromia region and (c) agro-ecology of Gudeya Bila wereda
Source: Authors

though there are some studies that tried to show the impact of pesticides on bees in Ethiopia, they cannot objectively quantify the level of risks to bees via application of pesticides for the control of other pest incidences. For example, Fikadu (2020) studies pesticides use, practice and its effect on Ethiopian honeybee; nevertheless, the study was based on secondary data and thus the finding was more general. The objective of this study is to assess pesticide application, use and its implications on honey bees.

MATERIALS AND METHODS

The study was conducted in Gudeya Bila wereda/district, which is among the weredas in the East Wollega zone in Oromiya Region, Ethiopia (Figure 1). The wereda has 13 rural *kebeles (*lowest administration structure below district/wereda in Ethiopia) and 2 local councils (Bila and Jare). Geographically, the wereda is located between 9°11'00'' - 9°30'00'' North latitude and 36°42'00'' to 37°10'30'' East longitude (Figure 1). The elevation of the wereda ranges from 1370 to 2996 m a.s.l. Thus, according to local classification (Hurni, 1998), the wereda has three agro-ecological zones, that is, *dega* (cool, humid highlands, 2300 to 2996 m a.s.l.), *weyna dega* (mild, sub-humid highlands, 1500 to 2300 m a.s.l.), and *kolla* (warm, semi-arid, lowlands, 1370 to 1500 m a.s.l.) that cover about 13.5, 67 and 19.5%, respectively (Figure 1). Gudeya Bila wereda has two rainy seasons, where the main rainy season occurs between June and September while the second occurs between October and May, with an average annual rainfall of 1100 to 1950 mm. The temperature of the district varies between 11 and 23°C, respectively. Major crops grown in the wereda include maize (*Zea mays*), teff (*Eragrostis tef*), beans (*Phaseolus vulgaris*) and some kinds of fruit and vegetables.

The study followed a quantitative and qualitative approach. Questionnaire focusing on socio-demographic, beekeeping status, pesticide use and application practice, implications of pesticides to beekeeping and other various data collection methods such as household surveys, focus group discussions (FGDs), and key informants interviews (KIIs) and field observations were used to observe seasons of pesticide application, topographies of study area, and beekeeping status, circumstance or community like actions, opinions, skills, values, and expertise. The use data of most frequently applied pesticide by farmers through the survey were analysed for risks to bees using software PRIMET (Pesticide Risks In the Tropics for Man, Environment and Trade). It was done to have a more refined estimation of risks pose d to bees from the application of these pesticides based on the conceptual

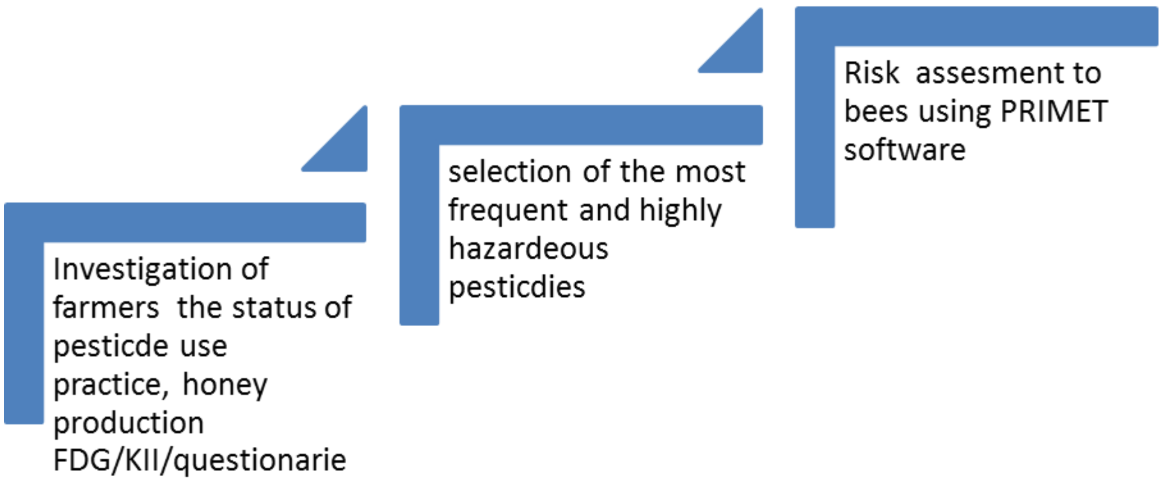


Figure 2. A conceptual framework of the study.
Source: Authors

framework indicated in Figure 2.

Target population, sampling design and sample size

The sampling frame for this particular study was rural farmers found in Gudeya Bila *wereda*. Multi- stage sampling technique was used to select the representative samples. The study area was selected purposefully and carefully so as to represent the *wereda* in terms of economic, socio-cultural, and physical factors like agro-ecology, and familiarity of the researcher to the study area. Therefore, at the first stage, the rural *kebeles* of the wereda were stratified by agro-ecology as *dega*, *weyna dega* and *kolla* and then the sample rural *kebeles* were selected randomly to represent the agro-ecological zones (Figure 1) by lottery method. Households or respondents were selected randomly from the sample *kebeles* agriculture office lists of farmers engaged in beekeeping. In addition to this, pesticide retailers were included in the sampling for FGD and KII to get information on pesticides selection and use status. Hence, it was appropriate to have a deep understanding of the pesticides use practice, application practice and beekeeping status of the study area.

The sample size of the study was determined or calculated using Taro Yamane sample size determination formulas with household number of sample *kebeles*, as given in Equation 1.

$$\mathrm{n} = \frac{N}{1+N(e)2} \quad (1)$$

$$n = \frac{1439}{1+1439(0.005)2} = 312$$

n = 312 sample sizes used for this study

where n-sample size, N-is number of households of sample *kebeles*, and e-the precision or sampling error which is 0.005.

As the proportion of respondents/households that is food secure is not known, 0.5 was used as p-value to obtain the sample size (312).

Out of the total respondents involved in the questionnaire survey: respondents were pesticide traders from whom data on pesticides were obtained and 304 respondents were farmer households who were interviewed in relation to pesticide use.

Data analysis

Qualitative and quantitative techniques were used to analyse the study data. Information obtained from key informant interview, focus group discussion and personal observation was analysed qualitatively. The SPSS software version 20 was used to analyse the quantitative data obtained from household survey.

For the risk assessment of in crop and off crop, an oral LD50 and a contact LD50 were available and taken from Pesticide Properties Data Base (PPBD) from which the lowest value was determined. Moreover, pesticide application rate was obtained from Ministry of Agriculture (Ethiopian) Plant Health Regulatory Directorate database (Equations 2 and 3) (Wipfler et al., 2014). The European Union (EU) trigger value of 50 was used, which was established based on empirical research. An assessment of observed bee killings (colony sound effects) for various pesticides and different application rates showed that for sprays a factor of the Exposure Toxicity Ratio (ETR) below 50 is always safe as no field incidents at ETR < 50. While a trigger value of above 400 for the ETR is considered highly risky for bees. This value is taken as the upper limit of the risk classification as shown for in-crop and off-crop situations of beehives from the pesticide application spots (Wipfler et al., 2014).

ETRin-crop = dose rate/ LD50 (2)

ETRoff-crop = (dose rate × drift factor)/ LD50 (3)

where Low risk: if ETR in-/off-crop situation is < 50, possible risk: if ETR in-/off-crop situation is between 50 and 400, gigh risk: if ETR in-/off-crop situation > 400.

Thus, risks of some frequently used pesticides were assessed using PRIMET software version 1.1.1.1 (Wipfler et al., 2014) and the household survey data as an input.

Depending on the ETR values, decision was made regarding the pesticide application using PRIMET software to determine the risk

Table 1. Type of beehives and income farmers obtained per production season.

Type of beehive survey households owning	Households reported		Households income from honey production		
	Frequency	%	Income (US dollars/season)	Households reported	
				Frequency	%
Traditional only	207	66.4	50 to 75	42	13.5
Transition only	71	22.7	76 to 100	16	5.1
Tradition, modern and transition	26	8.33	101 to 125	32	10.3
System Missing	8	2.6	>126	214	68.5
Total	312	100	System Missing	8	2.6
			Total	312	100.

Source: Author

level of a given chemical (pesticide) to honeybee. Hence, quantitative household survey data were analysed in Statistical Package for Social Sciences (SPSS) and the outputs of SPSS such as frequency of application, time interval for application, and methods of applications were subjected to PRIMET test. Among most frequently used pesticides, insecticides and herbicides were widely used. Insecticides are the more damaging types of pesticides to honeybees (Leska et al., 2021). Therefore, six types of insecticides which are most frequently used in the study area and anywhere in Ethiopia were selected and their risks were analyzed using PRIMET Version 1.1.1. Following Wipfler et al. (2014) method, LD_{50} name of pesticide chemical, name of the target crop, number of application, application methods, time interval of the application, scenarios of exposure (in-crop or off-crop), category of risk (as chronic or acute risk), pesticide drift factors, rate (that is, concentration of active ingredient per hectare) and target organism were entered into PRIMET software for risk assessment.

RESULTS AND DISCUSSION

Beekeeping status and income of survey households from beekeeping

The study area communities have been using different type of beehives, where most of the survey households (66.4%) have traditional hives (Table 1). As per FGD and KII, there were two forms of traditional beekeeping in the study area, which are forest and backyard based beekeeping. The communities have been practicing forest beekeeping by hanging traditional beehives on trees. This production method is marked by terribly low honey production. Commonly, the average amount of crude honey obtained from conventional (traditional) beehives is about 8 to 15kg/beehive/year (Beyene and David, 2007). Traditional husbandry is practiced with many fixed comb beehives, particularly in remote areas. The traditional beekeeping is carried out with minimum expense and labor input, thus farmers consider it as beneficial particularly for individuals leading a marginal life (Tessega, 2009). The second most widely used hives in the study area is transitional hive as reported by 22.8% households. A transitional framework type beehive is an intermediate form, which is characterized between conventional and modern beehive type. Kenyan Top-Bar (KTB) is a well- known and commonly used hive in the study area. Nearly 8.3% have three types of hives, while the rest 2.6% respondents did not engage in the beekeeping; they were pesticide retailers.

Honey bee could be produced two times in a year. As shown in Table 1, the survey revealed that the households obtain some income from beekeeping by selling the produced honey. Considerably larger proportion (68.6%) of respondents reported that they earn over 5,000 birr (125 USD) in one production season, while the remaining earn below this amount; that is, 13.5, 5.1 and 10.3% respondents reported that they earn 50 to 75 USD, 3001-4000 birr (76 to 100 USD) and 4000 – 5000 birr (101 to 125 USD) in each production season, respectively. This is in line with Ajebush (2018)'s finding who studied economic and ecological importance of beekeeping in Ethiopia.

Pesticides use and application practices

The two important activities for smallholder farmers in relation to pesticides are pesticide use (handling) and procurement (buying and selecting) practices (Mengistie et al., 2015). Concerning pesticides use all survey respondents (100%) reported that they use chemical pesticides in the regular agricultural activities purchasing from local dealers. Among the respondents very few (10.6%) know legality status of the suppliers and purchase from the legal source; while the remaining (89.4%) do not know even what illegal pesticide suppliers means (Table 2). Those who reported that they knew the illegal pesticides they have wrong perception on how to identify the illegal pesticides. As they do not know how to identify illegal pesticides by identifying registration number, lists of registered and label pesticides have to be written in English and their local language (Amharic).

The other important issue in pesticide management and use is reading application instructions written on the

Table 2. Survey household perception on inclusion of pesticide use in agricultural extension.

Questions	Responses	Frequency	Percent
Status of respondents on buying pesticides with and without labels	With label	106	34.0
	Without label	198	63.5
	Missing (system)	8	2.5
	Total	312	100
Do you read the instruction/label on the container during purchasing?	Yes	75	24
	No	237	76
	Total	312	100
Where do you mix pesticides?	Near water sources (river, canal, other sources)	226	72.3
	In the field	86	27.7
	Total	312	100
Fate of pesticide containers	Reuse	257	82.3
	Dispose in the field	55	17.7
	Total	312	100
What material do you use to mix the pesticide?	Knapsack	67	10.6
	open headed plastic containers	245	89.4
	Total	312	100
Are pesticide uses included in extension service package?	Yes	37	11.9
	No	275	88.1
	Total	312	100.0
Do you have sufficient and appropriate information on how to use pesticides	Yes	50	16
	No	262	84
	Total	312	100
Have you seen punished pesticide dealer for selling illegal pesticides by inspectors?	Yes	0	0
	No	8	2.6
	Don’t know	304	97.4
	Total	312	100
Do pesticide inspectors visit pesticide shops and you in the field while applying pesticides?	Yes	0	0
	No	312	100
	Total	312	100
Do you consider appropriate timing to apply pesticides in relation to beekeeping?	Yes	130	41.7
	No	174	55.7
	Missing (System)	8	2.6
	Total	312	100

Source: Author

pesticide containers. In this regard most of the respondents (76%) indicated that they never read the label during purchasing and do not strictly follow the instruction on the package while applying the pesticides; about 24% respondents read the label while purchasing. In addition, about 63.5% of the respondents purchase unlabeled pesticides. This means majority of the study area smallholder farmers purchase pesticides without any instruction or information. In converse, the Ethiopian Government Pesticide Registration and Control Proclamation Number 674/2010 part four (b) emphasized that pesticide importers or dealers have to prominently display a legible label approved by concerned body both in Amharic and English languages that cannot easily be detached (Negarit, 2010). Therefore, this indicates the legally registered pesticides always have labels in both Amharic and English and are approved by Ministry of Agriculture (regulatory body). This survey result on the reading and use of pesticide labels is much lower than the study conducted by Gesesew et al. (2016) in Southwest Ethiopia, which reported that 63.2% of smallholder farmers usually follow the instructions/labels written on pesticide containers.

The FGD participants indicated that some retailers sell pesticides with material having safety sheet but most retailers (62.5%) sell pesticides by pouring from the original containers into other container based on the customer request. This is illegal action according to pesticide registration and control proclamation number 674/2010.

The Agricultural Office has given little emphasis in incorporating pesticide use in agricultural extension services. As shown in Table 2, only 11.9% of the respondents know that pesticides use has been included in agricultural extension package. Therefore, very few (16%) survey respondents had sufficient and appropriate information on how to use pesticides.

Based on the FGD and KII, there are eight pesticide retailers in the study area but only five of them had certificate of competency and other legal requirements. All pesticide dealers replied that they began pesticide market in the last two years. All of them have agricultural education background, but all do not have information and knowledge about pesticide registration and they do not have list of registered pesticides in Ethiopia.

The result of household survey and qualitative research also revealed that there were no pesticide inspectors from Agricultural Office to control illegal pesticides and mode of their application. In relation to this, all respondents indicated that they never seen any inspectors and no pesticide dealer has been punished for selling illegal pesticides. Moreover, 56.3% the respondents reported that they apply agro-chemicals (pesticide, insecticide or herbicide) whenever their farm gets infested with weed, insect or disease without due consideration to the natural honeybee production calendar. This means they spray the chemicals even at blooming or flowering stage of the crop although this stage is very acute time for bee to make honey. The other pertinent activity that might affect beekeeping and other environmental factor is the pace and materials to prepare agro-chemical for application. In this regard, most of the farmers (72.7%) mix pesticides near water sources (mainly rivers, canal or other community water source) which are used by bees and local residents for drinking and cooking; while the rest 27.3% mix pesticides in the field where they spray the chemicals by fetching water used for missing the pesticides. This show there might be contamination of water from the containers used to mix pesticides and during the mixing process. This finding is in line with the research conducted by Belay and Alemayehu (2016) in the Central Rift Valley of Ethiopia on agro-chemical management and application practice. Majority (89.4%) of the survey households replied that they mix the pesticide in a knapsack and the rest mix in locally available open headed plastic containers. The other environmental and human health concern is the feat of the container, where 82.3% of the respondents indicated that they reuse the pesticide and other agro-chemical containers without enough rinsing methods. The rest respondents dispose the container in the field without considering where and how to dispose it. The practice of the community in managing pesticide container in the environment including beekeeping is worst compared to Belay and Alemayehu (2016)'s finding, who reported about 48% of the farmers reuse the container without enough rinsing methods. This finding supports the idea forwarded by Fikadu (2020) in the review on pesticide use practice and its effects on honey bee in Ethiopia. The author indicated that majority of Ethiopian beekeepers do not use any control measures for poisoning honey bees with chemicals.

Implications of pesticide use on beekeeping

The household survey and qualitative research (FGD and KIIs) revealed that the use of agro-chemicals including pesticide creates problem in beekeeping. Accordingly, 31.7% of the household survey respondents said they have seen bees die during or after application of pesticides and the bees also show different behaviour (Table 3). For example, the survey respondents (52.9 and 15.4%) indicated that the bees show aggressiveness symptoms and anomalous behaviour besides the observed deaths after and/or during the chemicals spray on crops. The survey result also showed that beekeepers and farmers think that bee colonies have been declining overtime due to their exposure after or during pesticides application. This is evidenced in the observed deaths, aggressiveness, and anomalous behavior of worker bees.

Different findings have also documented that the use of different pesticides could lead to a significant reduction of foraging activity of honeybees (Marinelli et al., 2004; Henry et al., 2012). In this regard, Henry et al. (2012) underlined that droplets and dust from the agro-chemical applications will fall directly on the bees traveling through or around the treated fields and wind will bring the small droplets and soil particles several meters away from the

Table 3. Implication of pesticide use on beekeeping.

Questions	Responses	Frequency	Percent
Which of the following will be observed after pesticides application around hives?	Aggressiveness	165	52.9
	Deaths	99	31.7
	Anomalous behaviour of worker bees as rolling	48	15.4
	Total	312	100.0
Do you displace your hives when applying pesticides nearby hive?	No	304	97.4
	Missing (System)	8	2.6
	Total	312	100.0

Source: Author

flower. Similarly, Marinelli et al. (2004) verified that one insecticide droplet of agro-chemicals could destroy a bee since the spray solutions contain concentrated doses of pollutant compounds, which could be the most commoncause behind the bee outbreaks.

The current study showed that almost all farmers (97.4%) did not move their hives to safe place during pesticide application (Table 3). This implies that honeybees are exposed to the damage of agro-chemicals related with application methods and safety measures. This result is supported by Fikadu (2020)'s finding who indicated that majority of Ethiopian beekeepers do not use any control measures for poisoning honey bees with chemical. Likewise, Sánchez-Bayo and Goka (2016) indicated that most of the time, bees are exposed to pollutants by the ingestion of pollen and nectar residues from infected seeds, whether from crops or from weeds across the fields. It is important to note that bees eat chemicals wherever they go and search for the most fitting flowers that provide ample pollen and nectar. Such crops are also more attractive than others; for example, canola (rape seed oil) yellow flowers, sunflowers, and many of the weeds that grow in and around the crops are more attractive to bees than potato plant flowers (Dötterl and Vereecken, 2010). In converse, farmers apply chemicals to these crops to control pest, insect, disease and weed. The forager bees take pesticide residues in pollen and nectar to their colonies and live inside the beebread and honey for quite some time (Orantes-Bermejo et al., 2010). These residues are then fed to the larvae and the queen as well, that are influenced by the forager bees in comparable ways. Bees also consume water in addition to sugar, to control their temperature (Schmaranzer, 2000). Pesticide compounds in the soil gradually get into the water and emerge in and above the lakes, creeks and rivers in rural areas; they are polluted with a combination of agrochemicals that can eventually be consumed by bees (Belden et al., 2007; Sánchez-Bayo and Goka, 2016; Zhu et al., 2014). Additionally, water pollution from spray applications, particularly from insecticides can impact honey bees. This is very critical for bumblebees and wild bees that prefer to drink from puddles, drainage ditches, rivers and lakes, and they are often eaten by forager bees if these waters are polluted with pesticide residues (Woodrow et al., 1989). Thus, these exposures of honey bees to pesticides cause the collapse of bee colonies.

Risk assessment results of selected pesticides using PRIMET software

According to FGDs and KII, carbaryl, chlorpyrifos, diazinon, fipronil, malathion and profenofos are among the most frequently used insecticide in the study area. Other similar works also confirmed the frequent use of these pesticides in Ethiopia (Teklu et al., 2021). Of these investigated pesticides that are risky to bees, carbaryl and chlorpyrifos are mostly used for the treatment of maize stalk borer. The risk assessment of carbaryl and chlorpyrifos using PRIMET software in this study area revealed 9107 and 3254 Exposure Toxicity Ratio (ETR) value respectively for carbaryl and chlorpyrifos in-crop scenario (Table 4). This showed that both insecticides are highly risky to honey bees. Similarly, assessment in United Kingdom by Mineau et al. (2008) revealed 50% probability of bee mortality at a trigger value of 400 for the ETR for numerous pesticides at different application rates.

Likewise, for off-crop scenario, the ETR value was 255 for carbaryl and 91.12 for chlorpyrifos sprayed on maize. This implies that there is possible risk if expected from both insecticides (Table 4). Pesticide exposure can have a sizable impact on the nutritional composition of royal jelly produced by honey bees and as a result can influence queen development. Oral exposure to pesticides in adult workers has been shown to influence nurse bee glandular physiology and could therefore impact royal jelly production (Böhme et al., 2018). As shown in Tables 2 and 3, the study area farmers do not

Table 4. Summary of risk assessment to bees in an in crop and off crop situation.

Pesticide	Crop	Application rate (kg/ha)	LD50 Oral/contact (µg/bee)	PNEC (g/ha)	PEC in crop	PEC of crop	In-crop ETR=PEC/ PNEC	off-crop ETR=PEC/PNEC
Carbaryl	Maize	1.275	0.14	0.14	1275	35.7	9107	255
Chlorpyrifos	Maize	0.192	0.059	0.059	192	5.376	3254	91.12
Diazinon	Maize	0.6	0.09	0.09	600	16.8	6667	186.7
Fipronil	Cabbage	0.05	0.00417	0.00417	50	1.4	120000	335.7
Malathion	Potato	0.75	0.16	0.16	750	21	4688	131.3
Profonefos	Faba bean	0.72	0.095	0.095	720	20.16	7579	212.2

ETR < 50 = low risk, 50<ETR < 400 , medium Risk, ETR >400 = high risk.
Source: Author

displace (move) beehives and select appropriate time during pesticide applicant. These practices would expose honey bees to pesticide poisoning. Both pesticides are used foliar in controlling crop pest and have a relatively high toxicity to bees compared to other pesticides (Johnson et al. 2010). Worker honey bees can forage in range up to 12 km around hive and, therefore, are frequently exposed to a dispersal of pesticide residues present in water, nectar and pollen (Mullin et al., 2010).

Diazinon is an insecticide registered to treat maize and sorghum stalk borers and armyworm in Ethiopia. In the study area, it was mainly used to treat maize and sorghum stalk borer. The ETR value of diazinon for in-crop scenario was 6667 and this value shows that diazinon is highly risky to honey bees (Table 4). For off-crop scenario the value of ETR was 186.7 and this value indicated diazinon can be classified in possible risk category. As a matter of fact, diazinon was known to be highly toxic to terrestrial invertebrates, bees and other beneficial insects following acute contact exposure, where acute LD50 for bees was 0.22 µg/one bee as per University of Hertfordshire (2013). In general, the toxicity of insecticides to honey bees increased with increase in the exposure time.

Fipronil is among the insecticides used mainly to treat termites in rice and aphids on cabbage. Fipronil ETR is 12×E4 or 120,000 and this value indicates fipronil was highly risky to honey bees for in-crop scenario (Table 4). For off-crop scenario, the ETR value of fipronil is 335.5 which can be classified under possible risk for honey bee. According to Narahashi et al. (2010), fipronil has an antagonistic action on gamma amino butanoic acid (GABA) neurotransmitters and glutamate-activated chloride channels (GluCls). Therefore, this pesticide/ insecticide can cause interactive changes in bees that embrace agitation, spasms, tremors, and paralysis (Zaluski et al., 2015). Fipronil is more noxious in sublethal doses, spoiling the motor activity of bees. Experimental exposure to dietary fipronil caused dose-dependent reductions in the longevity (days of exposure survived) of adult honey bees and fipronil can be lethal to honey bees in dietary exposures to the trace residues that typify those in nectar and pollen from treated crops (Mullin et al., 2010). Including fipronil, all insecticides assessed as indicator by PRIMET software were risky to honey bee. Therefore, protection measures must be taken to keep honey bees from pesticides poisoning during or after application.

Malathion is one of the most frequently used pesticides and is formulated locally by Adamitulu Pesticide processing company of Ethiopia in addition to imported ones. According to FGDs and KIIs, Malathion, in form of 50% EC formulation type, was mostly used in the study area to treat maize and sorghum stalk borer. For the in-crop scenario, the ETR value of malathion was 4688 which can be categorized as highly risky to honey bee (Table 4). Concerning off-crop scenario, the ETR of malathion was 131.3 that can be classified under possible risk to honey bee. As indicated earlier, bees eat chemicals including malathion wherever they go and search for the most fitting flowers that provide ample pollen and nectar.

Profenofos is another pesticide categorized under organophosphate chemical group. As shown in Table 4, the ETR values of profenofos for in-crop and off-crop scenario were 7579 and 212.2 respectively and thus categorized under high and possible risk to honey bees in the respective order. From the above PRIMET output as an ETR value showed that all (six) pesticides types namely: carbaryl, chlorpyrifos, diazinon, malathion, fipronil and profonefos are highly and possibly risky to honey bees for in-crop and off-crop scenarios considering each chemical (Table 4).

Other exposure routes of bees to pesticides come from water pollution due to drift from spray applications, particularly from insecticides (Woods et al., 2003). Honey bees, bumblebees and wild bees prefer to drink from puddles, drainage ditches, rivers and lakes, and they are often eaten by forager bees if the waters are polluted with pesticide residues. These facts indicate that when bees are exposed to pesticides their colonies are under risk of damage by pesticides poisoning. Wild bees (*Osmia bicornis*) exposed to thiamethoxam and clothianidin sub lethal levels had their reproductive performance reduced by 50% (Sandrock et al., 2014a), while honey bee queens experienced exceptionally high supersede rates (60%) (Sandrock et al., 2014b); colonies of bumble bees (*Bombus terrestris*) exposed to thiamethoxam sub lethal levels did not perform and produced 85% (Whitehorn et al., 2012). In forager bees, sub lethal doses of neonicotinoid insecticides often induce disorientation in the state of mind (Decourtye and Devillers, 2009). Recent global decline on pollinators including honey bees has been reported owing to several factors and unwise use and practices of pesticides honey bee productivity is affected by the indiscriminate use of agrochemicals, lack of knowledge, pest and predators (Fikadu, 2020).

CONCLUSION AND RECOMMENDATIONS

In this study, six pesticides were identified to be used frequently by farmers that are considered to be used frequently and at the same time risky to bees namely, carbaryl, chlorpyrifos, diazinon, malathion, fipronil and profonefos. Farmers' awareness in considering the presence of bees in pesticide applications and caring for bee hives that are present in/off-crop situation is found to be less. Moreover, concern to protect human and environmental health in general is minimal. The dominant type of bee hive present in the study area is traditional followed by transitional one. Thus it is common to see bee hives hanged in trees in the middle of farming areas. Thus, in-crop risks form application of pesticides is found to be high. This is evidenced by farmers reporting to observe serious physical, behavioural and physiological changes of the honey bees after application of pesticides in the area.

Risk assessment for the selected six pesticides revealed that all the six pesticides pose high risk to bees if applied in an in-crop situation. Possible risks are also indicated for bee hives available in an off-crop situation. Therefore, farmers and retailers need to be constantly informed about hazards of theses pesticides so that the current haphazard handling of pesticides is improved. Concerning application practice, there must be legal bindings or directives that obligate pesticide users and farmers to notify beekeepers of the neighbouring areas before application of these pesticides. Protection measures like removing or covering beehives during application, avoiding application of pesticide on time of flowering of either to main or fodder crops, application only after sunsets need to be adopted for honey bees risky pesticides. Pesticide registration and control department of Ministry of Agriculture should notify and regulate the registrants or agents of pesticides traders to indicate on the labels clearly the toxicity status of pesticides. Moreover, it is important to translate labels to languages appropriate to local situation.

CONFLICT OF INTERESTS

The authors declare no financial, commercial and legal conflict of interest directly or indirectly related to this published article.

ACKNOWLEDGEMENTS

The authors thank the Addis Ababa University and the Ministry of Agriculture of Ethiopia for the successful completion of this study.

REFERENCES

Ali I, Jain CK (1998). Groundwater Contamination and Health Hazards by Some of the Most Commonly Used Pesticides. Current Science 7(10):1011-14. Available at: http://www.jstor.org/stable/24101777

Al-Shaalan NH, Ali I, Zeid A, Alothman A, Al-Wahaibi LH, Alabdulmonem H (2019). High performance removal and simulation studies of diuron pesticide in water on MWCNTs. Journal of Molecular Liquids 289:111039.

Amera T, Abate A (2008). An assessment of pestucide use, practice and hazards in the Centeral Rift Valley. Report for the African Stockpiles Program: Institute for Sustainable Development, Ethiopia and PAN UK, London.

Belay FD, Alemayehu OW (2016). The Significance of Honey Production for Livelihood In Ethiopia. Journal of Environment and Earth Science 6(4):46-53.

Belden JB, Gilliom RJ, Martin JD, Lydy MJ (2007).Relative toxicity and occurrence patterns of pesticide mixtures in streams draining agricultural watersheds dominated by corn and soybean production. Integrated Environmental Assessment and Management: An International Journal 3(1):90-100.

Beyene T, Davide P (2007). Ensuring Small Scale Producers in Ethiopia to Achieve Sustainable and Fair Access to Honey Markets. Paper Prepared for International Development Enterprises (IDE)and Ethiopian Society for Appropriate Technology (ESAT).

Böhme F, Bischoff G, Zebitz CPW, Rosenkranz P, Wallner K (2018). From field to food - will pesticide-contaminated pollen diet lead to a contamination of royal jelly? Apidologie 49(1):112-119,

Brühl CA, Schmidt T, Pieper S, Alscher A (2013). Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline? Scientific Reports. 3(1):1-4.

Chakrabarti P, Rana S, Sarkar S, Smith B, Basu P (2015). Pesticide-induced oxidative stress in laboratory and field populations of native honey bees along intensive agricultural landscapes in two Eastern Indian states. Apidologie 46(1):107-129.

Chauzat MP, Faucon JP, Martel AC, Lachaize J, Cougoule N, Aubert M (2006). A survey of pesticide residues in pollen loads collected by honey bees in France. Journal of Economic Entomology 99(2):253-262.

Central Statistical Agency (CSA) (2011). Key Findings of the 2008/2009-2010/11 agricultural sample surveys for all sectors and seasons country summery. Central Statistics Authority. Addis Ababa, Ethiopia.

Decourtye A, Devillers (2009). Ecotoxicity of Neonicotinoid Insecticides to Bees. In: Thany SH, editor. Advances in Experimental Medicine and Biology - Insect Nicotinic Acetyl-choline Receptors. Austin, TX: Landes Bioscience pp. 85-95.

De Grandi-Hoffman G, Chen Y, Simonds R (2013). The effects of pesticides on queen rearing and virus titers in honey bees (*Apis* *mellifera* L.). Insects 4(1):71-89.

Dötterl S, Vereecken NJ (2010). The chemical ecology and evolution of bee–flower interactions: a review and perspectives. Canadian Journal of Zoology 88(7):668-697.

Ebi K, Padgham J, Doumbia M, Kergna A, Smith J, Butt T, McCarl B (2011). Smallholders adaptation to climate change in Mali. Climatic Change 108(3):423-436.

Fikadu Z (2020). Pesticides use, practice and its effect on honeybee in Ethiopia: a review. International Journal of Tropical Insect Sciences 40(3):473-481.

Gesesew HA, Woldemichael K, Massa D, Mwanri L (2016). Farmers Knowledge, Attitudes, Practices and Health Problems Associated with Pesticide Use in Rural Irrigation Villages, Southwest Ethiopia. PLOS ONE 11(9):e0162527.

Gupta VK, Ali I, Aboul-Enein HY (2003).Chirality: A challenge for the Environmental Scientists. Current Science 84(2):152-156.

Henry M, Béguin M, Requier F, Rollin O, Odoux JF, Aupinel P, aptel J, Tchamitchian S, Decourtye A (2012). Common Pesticide Decreases Foraging Success and Survival in Honey Bees. Science 336(6079):348-350.

Hurni H (1998). Agro-ecological belts of Ethiopia: explanatory notes on three maps at a scale of 1:1,000,000. Research report, Soil Conservation Research Program, Addis Ababa

Kenesa T (2018). Status of Beekeeping in Ethiopia- A Review. Dairy and Veterinary Sciences Journal 8(4):555743.

Kerealem E, Tilahun G, Preston TR (2009). Constraints and prospects for apiculture research and development in Amhara region, Ethiopia. Livestock Research and Rural Development 21(10):172.

Khan DA, Shabbir S, Majid M, Naqvi TA, Khan FA (2010). Risk assessment of pesticide exposure on health of Pakistani tobacco farmers. Journal of Exposure Science and Environmental Epidemiology 20(2):196-204.

Knapton D, Burnworth M, Rowan SJ, Weder C (2006). Fluorescent Organometallic Sensors for the Detection of Chemical Warfare Agent Mimics. Angewandte Chemie, 118(35):5957-5961.

Konstantinou JK, Hela DG, Albanis TA (2006). The status of pesticide pollution in surface waters (rivers and lakes) of Greece. Part I. Review on occurrence ad levels. Environmental Pollution 141(3):555-70.

Leska A, Nowak A, Nowak I, Górczyńska A (2021). Effects of insecticides and microbiological contaminants on Apis mellifera health. Molecules 26(16):5080.

Marinelli E, Pulcini P, Margio C, De Pace F, Allegrini F, Persona Oddo L (2004). Oxalic acid by Varrox to Varroa control in Central Italy. Apiacta 39:39-43.

Melaku G, Shifa B, Azage T, Negatu A, Lulseged B (2008). Approaches, methods and processes for innovative apiculture development: Experiences from Ada'a-Liben Woreda, Oromia Regional State, Ethiopia. IPMS of Ethiopian Farmers Project Working Paper 8.

Mengistie BT (2016). Environmental Governance of Pesticides in Ethiopian Vegetable and Cut Flower Production: PhD thesis, Wageningen University and Research.

Mengistie BT, Arthur Mol PJ, Peter O (2015). Pesticide use practices among smallholder vegetable farmers in Ethiopian Central Rift Valley. Environmental Development and Sustainability 19(1):301-324.

Mineau P, Harding KM, Whiteside M, Fletcher MR, Garthwaite D, Knopper LD (2008). Using reports of bee mortality in the field to calibrate laboratory-derived pesticide risk indices. Environmental Entomology 37(2):546-554.

Mullin CA, Frazier M, Frazier JL, Ashcraft S, Simonds R, Vanengelsdorp D, Pettis JS. (2010). High levels of miticides and agrochemicals in North American apiaries: implications for honey bee health. PLoS One 5(3):e9754.

Naik AA, Wanganeo A (2014). Occurrence of some pesticides in Bhoj wetland Bhopal and their effect on phytoplankton community: An ecological perspective. Journal of Toxicology and Environmental Health Sciences 6(9):170-180.

Negarit G (2010). Pesticide registration and control proclamation. https://chilot.me/knowledge-base/proclamation-no-674-2010 pesticide-registration-control-proclamation/ Accessed on July 6, 2022.

Net S, Delmont A, Sempere R, Paluselli A, Ouddane B (2015) Reliable quantification of phthalates in environmental matrices (air, water, sludge, sediment and soil): A review. Science of the Total Environment 515:162-180.

Nuru A (2007). Atlas of pollen grains of major honeybee flora of Ethiopia. Holetta bee research center. Holeta, Ethiopia.

Sánchez-Bayo F, Goka K (2016). Impacts of pesticides on honeybees. Beekeeping and Bee Conservation - Advances in Research Chapter: 4Publisher: InTech Open Science Editors: Emerson D. Chambo. DOI: 10.5772/62487

Sandrock C, Tanadini LG, Pettis JS, Biesmeijer JC, Potts SG, Neumann P (2014a). Sub lethal neonicotinoid insecticide exposure reduces solitary bee reproductive success. Agricultural Forestry and Entomology 16(2):119-28.

Sandrock C, Tanadini M, Tanadini LG, Fauser-Misslin A, Potts SG, Neumann P (2014b). Impact of chronic neonicotinoid exposure on honeybee colony performance and queen supersedure. Public Library of Science One 9(8):e103592.

Sheridan K (2017). Bee-harming pesticides in 75 percent of honey worldwide: study. https://phys.org/news/2017-10-bee-harming-pesticides-percent-honeyworldwide.html. Accessed on October 8, 2017.

Teklu BM, Hileslassie A, Mekuria W (2021). Pesticides as water pollutants and level of risks to environment and people: an example from Central Rift Valley of Ethiopia. Environment, Development and Sustainability 24(4):5275-5294.

Tessega B (2009). Honeybee Production and Marketing Systems, Constraints and opportunities in Burie District of Amhara Region, Ethiopia. A Thesis Submitted to the Department of Animal Science and Technology, School of Graduate Studies Bahir dar University.

University of Hertfordshire (2013). The Pesticide Properties Data Base (PPDB) developed by the Agriculture & Environment Research Unit (AERU), University of Hertfordshire, UK. http://www.eu-footprint.org/ppdb.html.

Wipfler EL, Adriaanse PI, ter Horst MMS, Vlaming J, van den Brink PJ, Peeters FM, Deneer JW, Boesten JJTI, Groenwold JG (2014). PRIMET_ Registration_Ethiopia_1.1, technical description and manual. In: A Decision Support System for Assessing Pesticide Risk in the Tropics to Man, Environment and Trade, for Pesticide Registration in Ethiopia. Altera report 2573, Wageningen, The Netherlands.

Whitehorn PR, O'Connor S, Wackers FL, Goulson D (2012). Neonicotinoid pesticide reduces bumble bee colony growth and queen production. Science 336(6079):351-352.

Woodrow JE, Wong JM, Seiber JN (1989). Pesticide residues in spray aircraft tank rinses and aircraft exterior washes. Bulletin of Environmental Contamination and Toxicology 42(1):22-29.

Yirga G, Teferi M (2010). Participatory Technology and Constraints Assessment to Improve the Livelihood of Beekeepers in Tigray Region, northern Ethiopia, Momona Ethiopian Journal of Science 2(1):76-92.

Zaluski R, Kadri SM, Alonso DP, Martins Ribolla PE, de Oliveira Orsi R (2015). Fipronil promotes motor and behavioral changes in honey bees (*Apis mellifera*) and affects the development of colonies exposed to sub lethal doses. Environmental Toxicology and Chemistry 34(5):1062-1069.

Zhang WJ, Wopke van der Werf, Pang Y (2011). A simulation model for vegetable-insect pest-insect nucleopolyhedrovirus epidemic system. Journal of Environmental Entomology 33(3):283-301.

Zhu W, Schmehl DR, Mullin CA, Frazier JL (2014). Four common pesticides, their mixtures and a formulation solvent in the hive environment have high oral toxicity to honey bee larvae. Public Library of Science One 9(1):e77547.

Related Journals: