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Environmental load of pesticides used in conventional sugarcane production in Malawi

Trust Kasambala Donga[a,*], Ole Martin Eklo[a,b]

[a] Nowergian University of Life Sciences, Campus Ås, Universitetstunet 3, 1433, Ås, Norway
[b] Norwegian Institute of Bioeconomy Research, P.O. Box 115, NO-1431, Ås, Norway

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ABSTRACT

The sugarcane industry is the third largest user of pesticides in Malawi. Our aim with this study was to document pesticide use and handling practices that influence pesticide exposure among sugarcane farmers in Malawi. A semi-structured questionnaire was administered to 55 purposively selected sugarcane farmers and 7 key informants representing 1474 farmers in Nkhata Bay, Nkhotakota and Chikwawa Districts in Malawi. Our results indicate that herbicides and insecticides were widely used. Fifteen moderately and one extremely hazardous pesticide, based on World Health Organization (WHO) classification, were in use. Several of these pesticides: ametryn, acetochlor, monosodium methylarsonate and profenofos are not approved in the European Union because of their toxicity to terrestrial and aquatic life, and/or persistence in water and soil. Farmers (95%) knew that pesticides could enter the human body through the skin, nose (53%) and mouth (42%). They knew that pesticide runoff (80%) and leaching (100%) lead to contamination of water wells. However, this knowledge was not enough to motivate them to take precautionary measures to reduce pesticide exposure. Farmers (78%) had experienced skin irritation, 67% had headache, coughing and running nose during pesticide handling. Measures are in place to reduce pesticide exposure in the large estates and farms operated by farmer associations. Smallholder farmers acting independently do not have the resources and capacity to minimize their exposure to pesticides. There is need to put in place pesticide residue monitoring programs and farmer education on commercial sugarcane production and safe pesticide use as ways of reducing pesticide exposure.

1. Introduction

Sugarcane is the second most valuable crop after tobacco contributing 9–12% of Malawi's foreign exchange earnings (FAO, 2015). In 2017, large estates contributed 83% to national production compared to 17% for smallholder farmers (ILLOVO, 2017). The Government of Malawi supports smallholder production of sugarcane as a sustainable way of reducing poverty (Chinsinga, 2017). Hence, the number of smallholder sugarcane famers also known as outgrowers has been increasing since 2011. However, since 2014, the amount of sugarcane processed at sugar mills from smallholder farmers has been decreasing while it has remained constant for the estates (ILLOVO, 2017). There are many contributing factors to the low sugarcane tonnage by smallholder farmers. Pest occurrence and poor crop management may be some of the factors (Tena et al., 2016).

Pesticides are widely used throughout the sugar industry. The industry consumes 10–15% of pesticides imported in Malawi (GOM, 2017). Herbicides recommended for use in sugarcane production in Malawi include ametryn, atrazine, monosodium methylarsonate (MSMA), 2-methyl-4-chlorophenoxyacetic acid (MCPA), s-metolachlor, pendimethalin, diuron, acetochlor and glyphosate (GOM, 2017; Agricane, 2011). Glyphosate is a pre-emergent herbicide for the control of emerged annual and perennial weeds, and for crop/ratoon eradication. It is a recommendation that farmers apply glyphosate when the land is lying in fallow. Atrazine and pendimethalin are also pre-emergent herbicides for the control of annual broadleaf and some grass weeds. Application of these herbicides is at the time of planting/rattooning and before weed emergence. Ametryn and MSMA are post-emergent herbicides for control of most annual and broadleaf weeds. Some herbicides such as acetochlor, atrazine and glyphosate are both pre -and post-emergent herbicides. Several insecticides including chlorpyrifos and profenofos have government approval (GOM, 2017).

The undesirable effects of pesticides on the environment and human health are widely recognized. Pesticides can pollute the environment through pesticide runoff, drift, leaching and bioaccumulation (Mostafalou and Abdollahi, 2013; Wang et al., 2011; Weichenthal et al., 2010). The pesticide dichlorvos is an organophosphate fumigant pesticide that has no approval in the European Union (EU). It is highly

* Corresponding author. Plant Sciences Department, Nowergian University of Life Sciences, Campus ÅS, Universitetstunet 3, 1433, Norway.
E-mail address: trust.kasambala.donga@nmbu.no (T. Kasambala Donga).

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toxic, has a high tendency to bioaccumulate (PPDB, 2017). Even though glyphosate is considered to have low mammalian toxicity (Tarazona et al., 2017), its intensive use leads to groundwater contamination, herbicide resistance and inhibition of plant growth (Cederlund, 2017; Schryver et al., 2017; Van Stempvoort et al., 2016). Glyphosate is highly discussed in the EU because of possible carcinogenetic potential (EC, 2017). Glyphosate has approval for use in the EU until 2022 (PPDB, 2017).

The Government of Malawi acknowledges that pollution of waterbodies, air, soil and food due improper handling, storage and disposal of pesticides is of high concern (GoM, 2010). Hence, there are laws and policies for regulating pesticides. The Pesticides Act No. 12 of 2000 regulates the management of import, export, manufacture, distribution, storage, disposal and use of pesticides in Malawi (GoM, 2001). The integrated pest management plan (IPM) set in 2013 seeks to promote the use of environmentally friendly practices in major crops (GOM, 2017). IPM 'means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms' (EU Directive 2009/128/EC). Only pesticides with the least potential for environmental contamination can be included in IPM programs (FAO, 2014). The major problem in implementing successful IPM programs in Malawi is a lack of, or insufficient data on environmental pesticides load – toxicity resulting from pesticides. Hence, the main objectives of this work were to determine the environmental and health effects associated with pesticides used in sugarcane production in Malawi.

2. Materials and methods

2.1. Sugarcane production in Malawi

Sugarcane is vegetatively propagated using cane setts (stem cutting having 3–6 internodes). The recommended seed cane rate is 8–10 ton per hectare. Row spacing for irrigated sugarcane is 1.5 m and 1.0 m for rain fed cane. Either 1.5 or double cane setts are planted end-to-end in furrow. The initial sugarcane planted is plant cane and the subsequent crop arising from remnants of harvest of this initial crop is ratoon cane. Herbicides are applied on a calendar basis. Insecticides and acaricides are applied based on action thresholds. Fields are allowed to dry for 30 days before being burned and manually harvested. The act of burning sugarcane concentrates sucrose and drives away snakes and crocodiles.

There is a sugar mill at Dwangwa Estate in Nkhotakota and in Nchalo Estate in Chikwawa owned by ILLOVO Sugar Malawi Limited. Associated with these mills are smallholder farmers growing rainfed or irrigated sugarcane on contracts. These farmers acquire farm inputs on credit from registered farmer associations (Agricane, 2011). It is important to note that some associations perform agricultural operations such as herbicide applications, and pest and disease scouting on behalf of their members at a cost. In some associations, the farmer has the liberty of carrying out all the farm activities himself. These differences have consequences on farm practices among the various smallholder farmers.

2.2. Description of study sites

In Malawi, sugarcane is intensively cultivated in the Nkhata Bay, Nkhotakota, and Salima and Chikwawa districts (Fig. 1). The Nkhata Bay and Nkhotakota districts are high altitude areas with average annual rainfall of 1490 mm received mostly between December and April. The crop is rainfed in Nkhata Bay. The major source of irrigation to the sugar industry in Nkhotakota is Dwangwa River that drains into Lake Malawi. Chikwawa is a low altitude area (< 150 masl) with half of the average rainfall received in Nkhotakota. Water is drawn from the Shire River that flows out of Lake Malawi. Because of the topography of Chikwawa, the district is prone to annual flooding from water movement from the Shire Highlands and groundwater discharge into the river (Meyer and Heathman, 2015). In addition to sugarcane, many agricultural activities involving the use of pesticides take place on the catchments of the Dwangwa and Shire rivers, and Lake Malawi.

2.3. Study population

We conducted the survey between June 2015 and January 2016 in Nkhata Bay, Nkhotakota and Chikwawa (Fig. 1). We used purposive sampling to identify respondents from association membership lists and/or with the help of local agricultural extension officers. As of 2015, there were 2039 registered smallholder sugarcane farmers belonging to 18 associations in Malawi. Only farmers belonging to associations who had applied pesticides themselves during 2014/15 were included in the survey. We also interviewed the farm/section/estate/agriculture managers for Dwangwa and Nchalo Estates; Kabadwa Cane Growers Association, Dwangwa Smallholder Cane Growers Association and Independent Cane Growers in Nkhotakota; Limphasa Sugar Corporation Limited in Nkhata Bay; and Kasinthula Cane Growers' Association in Chikwawa. These represented 1474 smallholder farmers and served as key informants. A pre-coded and pre-tested semi-structured questionnaire was interviewer-administered to capture information practices and knowledge related to pesticides. 'Yes' and 'No' were the allowable responses to closed questions. There were also questions with four to six factors per question and respondents were required to choose the most important. Respondents were politely requested to provide their demographic details, pesticide application history and the source of money used for buying pesticides.

2.4. Sugarcane pests and pesticides used to control pests

During the above-described interviews, farmers were requested to give information on incidence and severity of pests on their sugarcane farms. Another question required the farmers to rank the pests in order of importance. A pesticide knowledge section of the questionnaire collected information on whether the farmers knew the names of recommended pesticides, their application rates (quantity of pesticide mixed a specific water volume in a sprayer) and frequency. A series of closed questions helped the interviewer to capture data on type and timing of pesticide application. The questionnaire had questions also on effectiveness of the pesticides they have used.

2.5. Environmental pesticide load

Except in commercial estates, the majority of farmers in Malawi do not keep pesticides records (Tebug et al., 2012). This limited our choice of pesticide risk assessment models. Therefore, environmental pesticide load was determined using the environmental impact quotient (EIQ) model. The EIQ model is easier to use and requires only a few input data. The EIQ model is widely used for comparing different pesticide strategies and the environmental impact of pesticides used in agriculture (Kromann et al., 2011; FAO, 2008; Eklo et al., 2003). The EIQ model summarizes all pesticides used during the season, thus giving a total score for the environmental load (Kovach et al., 1992). Pesticide data: active ingredients (a.i.) quantity (in grams, g), application rates (g.a.i.) per hectare (ha) obtained from the questionnaire survey was entered into the EIQ model. Pesticide data pertaining to farmers who could not remember the quantities of pesticides they had used in 2014/15 were excluded in the calculation of environmental load. We used the online EIQ calculator on the Cornell University website (NYSIPM, 2017). In the online calculator, the application rate was given in g.a.i

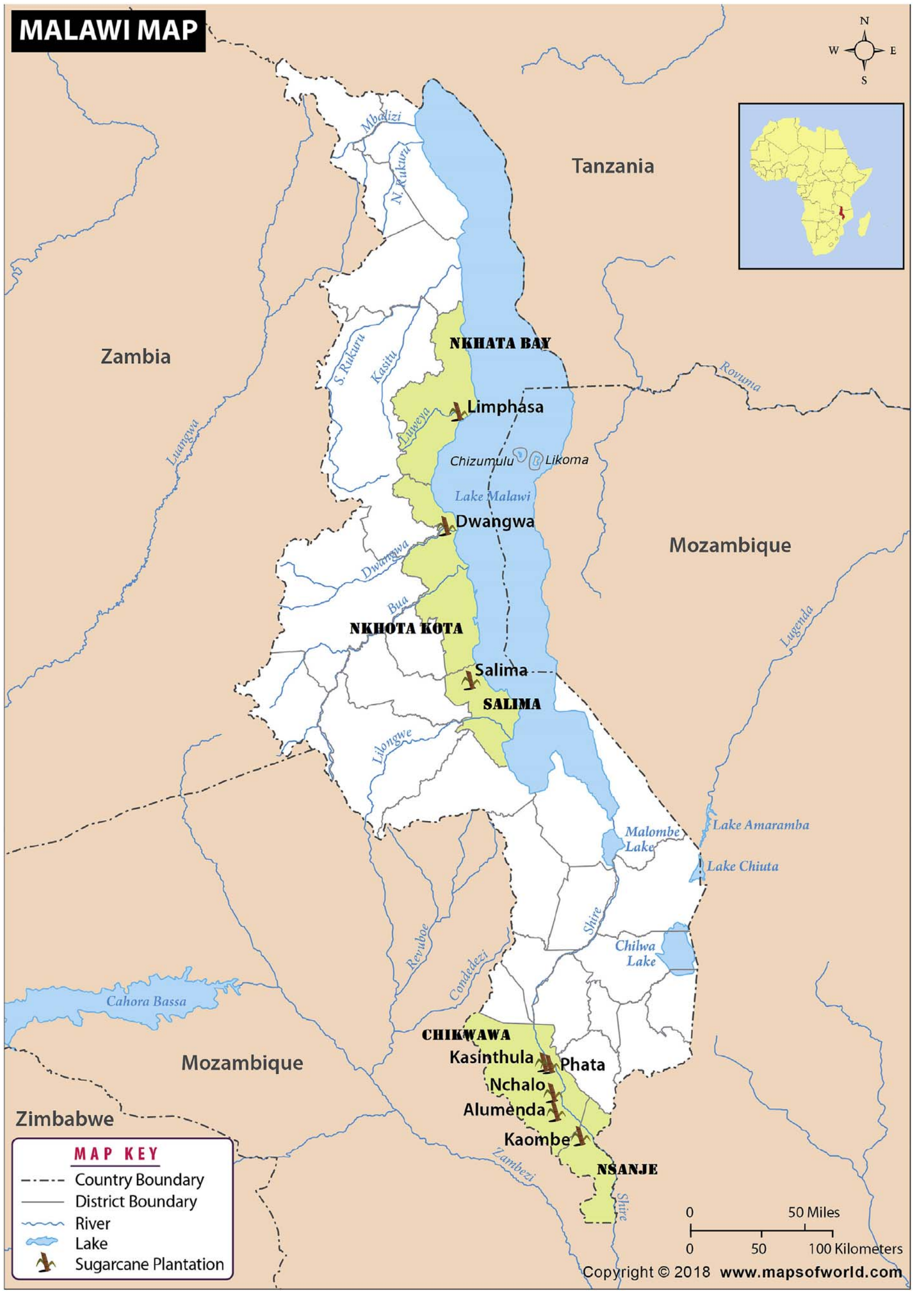

Fig. 1. Map of Malawi showing the location of sugarcane plantations and study sites in Nkhata Bay, Nkhotakota and Chikwawa Districts.

per 100 m^2. We also consulted the World Health Organization (WHO) recommended classification of pesticides by hazard and guidelines to classification published in 2009.

2.6. Effects of pesticides used on human health

During the questionnaire survey stated above, respondents were asked to report acute effects of pesticides they had experienced. Knowledge about how pesticides could enter the human body, ground wells and food were also evaluated. Farmers' handling of obsolete pesticides, pesticide storage and disposal of pesticide containers was also documented.

2.7. Data analysis

All statistical analyses were conducted in the Statistical Package for the Social Sciences (SPSS) version 24. Descriptive statistics used were means and percentages. Cross tabulations and chi-square test (χ^2) were used to show how different groups of respondents answered the survey questions (Punch, 1998). For example, age and education level could affect a respondent's ability to apply the correct application rate of a pesticide. For each farm, the environmental impact (EI) of each active ingredient per hectare was calculated using the formula shown below:

EI per ha = EIQ x application rate (g. a.i. per ha) x % active ingredient x number of applications.

3. Results

3.1. Study population

We interviewed 42 smallholder farmers in Nkhotakota and 13 in Chikwawa districts and 6 key informants. The 13 farmers interviewed in Chikwawa do not sell their sugarcane to any sugar mill in Malawi. The majority of respondents had completed primary school (Table 1).

Table 1
Farmer's demographic data (n = 55).

Characteristic	No. respondents	% respondents
Age (years)		
20–29	5	9.1
30–39	9	16.4
> 40	41	74.5
Education		
None	1	1.8
Primary	38	69.1
Secondary	11	20.0
Tertiary	5	9.1
Sugarcane farming experience (years)		
< 5	35	66.0
5–10	7	13.2
> 10	11	20.8
Farm size (ha)		
< 5	43	78.2
5–10	8	14.5
> 10	4	7.3

Table 2
Pesticides used by sugarcane farmers in Malawi and their target pest.

Pesticide type	Active ingredient	Target pest(s)
Insecticide	Abamectin	RSM, thrips, aphids
	Acetamiprid	Aphids
	Carbosulfan	Stemborers
	Chlorpyrifos	Larvae and adult black maize beetles
	Cypermethrin	Aphids, stemborers
	Dichlorvos	Aphids, thrips
	Dimethiote	Aphids, thrips
	Profenofos	Thrips and RSM
	Imidacloprid	Thrips
Herbicides	Acetochlor	Annual grasses
	Ametryn	Annual broadleaf weeds and grasses
	Atrazine	Annual broadleaf weeds and grasses
	Diuron	Weeds and mosses
	Glyphosate	Most annual grasses
	MCPA	Broadleaf weeds and certain grasses
	MSMA	Grass, sedges, broad-leafed weeds
	Pendimethalin	Annual broad-leafed weeds
	S-metolachlor	Broad-leafed and annual grassy weeds

About 79% fully depended on farming for income while 12% owned businesses. The most common sugarcane variety grown was MN1 (45.0%) seconded by R570 (32.0%). None of the farmers had attended training on sugarcane production. All key informants were above 40 years, had training in agronomy and over 10 years of experience in sugarcane cultivation. Income source was the main determinant of planting date ($\chi^2 = 8.383$, $df = 3$, $p = 0.039$), October–December for rainfed cane and April–September for irrigated cane. Harvesting took place 12–15 months later.

3.2. Sugarcane pests and pesticides used to control pests

Considering pests together, weed infestation was a major pest in all the respondents' farms. Herbicides were applied in all the estates and 60% of the smallholder farms in Nkhotakota. No herbicides were applied on the farms of farmers we interviewed in Chikwawa. The fungal disease smut caused by *Sporisorium scitamineum* was the most reported pest (35%) followed by sugarcane mosaic virus disease (17%).

Rusts (*Puccinia melanocephela, P. fulvous* sp. Nov. and P. *kuehnii*) and ratoon stunt (*Leifsonia xyli* subsp *xyli*) diseases were mentioned by less than 5% of the respondents. Stemborers were the main insect pests (16%) reported followed by white grubs (10%, larva of *Heteronychus* spp). Termites (*Macrotermes* spp) and aphids (yellow sugarcane aphids, *Sipha flava*) were reported by less than 10% of the respondents. The incidences of these pests varied with production system. Outgrower farmers in Nkhotakota reported sugarcane mosaic virus disease as the main sugarcane disease. Smallholder farmers in Chikwawa frequently mentioned the incidence of Lepidopteran stemborers.

Key informants confirmed the occurrence and identity of the pests reported by smallholder farmers. They also provided the situation on the estates and smallholder farms managed by farmer associations and a list of recommended pesticides. In addition to the pests reported by farmers, the following pests occurred on the estates: unidentified species of mealy bug (Pseudococcidae), leaf roller moth larvae (Lepidoptera: Noctuidae), earth pearl or margarodes scale (Margarodidae), scale insects (Coccidae) and grasshoppers; nematodes; sugarcane aphid (*Melanaphis sacchari*) sugarcane thrips (*Fulmekiola serrata*), and red spider mites, RSM (*Tetranychus urticae*). Only half of these were considered economic pests and warranted induction of control mechanisms. The incidence of yellow sugarcane aphids was highest in Chikwawa (Nchalo Estate and farms belonging to the Kasinthula Cane Growers Association). No insect pests or fungal diseases were reported at the Limphasa Sugar Company in Nkhata Bay.

The farmer's decision to start using pesticides was based on advice of extension workers 52%, pesticide label 26% and their own judgement 19%. However, the decision to apply herbicides was dependent on farm size ($\chi^2 = 8.000$, $df = 3$, $p = 0.046$). Only half of the farmers with secondary school education could understand the information indicated on the pesticide label ($\chi^2 = 35.616$, $df = 12$, $p = 0.000$). Those with primary education relied equally on extension workers and fellow farmers on pesticides related issues ($\chi^2 = 32.716$, $df = 3$, $p = 0.000$). Nevertheless, pesticide(s) a farmer actually used was dependent on pesticide availability ($\chi^2 = 7.700$, $df = 3$, $p = 0.006$). Timing of pesticide application was based on pest occurrence ($\chi^2 = 27.543$, $df = 16$, $p = 0.036$).

Although all respondents reported sugarcane diseases, no pesticides were used to manage them. Instead, cultural methods such as varietal resistance, use of disease free seed, sterilizing cutting equipment and manual removal of diseased plants were employed. Insecticide were applied on large estates and farmers' fields in Chikwawa. The insecticides acetamiprid and cypermethrin were used to manage aphids while four different insecticides controlled thrips. The organophosphate chlorpyrifos was used to control black maize beetles (Table 2).

Smallholder farmers we interviewed in Chikwawa did not spray any herbicides on their farms. Herbicides were routinely applied in 60% of outgrowers' fields in Nkhotakota, large estates and association-managed farms. Forty-four percent of these farmers applied herbicides as cocktails containing 2 or 3 herbicides. Commonly used herbicides were ametryn, atrazine, MSMA, MCPA and glyphosate (Table 2). Herbicide application rates for planted and ratoon sugarcane were different. For instance, for planted cane, the recommended rate for ametryn is 2.40 L/ha compared to 1.8 L/ha for ratoon cane. Atrazine has three application rates (L/ha): 2.70 for planted cane, 2.40 and 2.25 for ratoon cane, respectively. Application rates of ametryn (mean = 1710.00, $p = 0.000$), MSMA (mean = 2259.49, 1372.369, $p = 0.000$) and MCPA (mean = 768.00, $p = 0.012$) differed significantly among the smallholder farmers in Nkhotakota. According to key informant interviews, glyphosate and acetochlor was used to terminate weeds from waterways, spot and perimeters, and for crop eradication. Fusilade forte 150 EC (fluazifop-p-butyl 150 g/L) is a ripener while ethrel 480 EC (ethephon 480 g/L) is a flower suppressant used on large estates. All respondents used 20 L knapsack and 15 L jacto sprayers.

We found that large estates had some elements of IPM in place for managing arthropod pests. Based on key informant interviewed, there are action thresholds for insecticide application. To minimize spider mites infestations, trash/tops remaining after cane burning and haulage is practiced at Nchalo Estate. The egg parasitoid *Trichogramma chilonis* (at a rate of 2.5 c.c ha^{-1}, six releases in a growing season beginning from 4th month onwards at 15 days interval) is used to control stemborers. Scrap tobacco stems were used to manage maize black beetles. For management of all pests, each variety has less than 30% in the

Table 3
Active ingredients, WHO toxicity class and EIQ values for pesticides used by sugarcane growers in Malawi.

Pesticide (active ingredient)	WHO toxicity class[a]	Application rate (a.i. g ha^{-1}) range	a.i. EIQ	EI per ha
Agromectin 18 EC (Abamectin 18 g/L)	Ib	21.6	34.7	12.0
Acetamiprid (acetamiprid 200 g/L)	II	24–300	28.7	12.3–153.8
Marshal 250 EC (25% v/v carbosulfan)	II	281.25	50.7	304.7
Chlorpyrifos 500 EC (500 g/L chlorpyrifos)	II	750	26.9	898.3
Cypermethrin 200 EC (200 g/L cypermethrin)	II	37.5–600	36.4	24.3–389.2
Dichlorvos EC (organophosphate 1000 g/L)		1500	53.3	7129.0
Dimethiote 40 EC (400 g/L dimethoate)	II	224	33.5	267.7
Profenothrin 440 EC (40% of profenofos + 4% cypermethrin)	II	440	59.5	934.8
Bandit 350 SC (350 g/L Imidacloprid)	II	700	36.7	802.4
Harness 960 EC (960 g/L acetochlor)	III	1152–1600	19.9	1959.5–2721.6
Ametryn 500 SC (500 g/L triazine)	II	465–3750	24.2	501.6–4044.9
Atrazine 500 SC (485 g/L atrazine + 15 g/L other triazine)	III	750–1800	22.9	764.5–1834.8
Diuron 800 SC (diuron 800 g/L)	III	1350	26.5	2550.5
Roundup (510 g/L glyphosate)	III	324–3570	15.3	159.5–2490.2
MCPA (400 g/L phenoxyacetic acid)	II	480–3840	36.7	628.2–5025.2
MSMA 720 SL (720 g/L organic arsenical)	II	670–3564	18	774.7–4120.9
Metolachlor 960 EC (s-metolachlor)	III	1080	12.5	1156.2
Pendimethalin 330 EC (dinitroaniline 330 g/L)	II	742.5	30.2	659.5

[a] Ib: highly hazardous; II: moderately hazardous; III: slightly hazardous (WHO, 2009).

Table 4
Ecotoxicology parameters of pesticides used by sugarcane growers in Malawi.

Active ingredient	Approval status in the EU	Mammalian toxicity (oral) level	Toxicity to honeybees	Birds	Aquatic life
Abamectin[a]	✓				
Acetamiprid	✓	M	H	H	H
Carbosulfan	x[d]	H	H	H	H
Chlorpyrifos	✓	H	H	H	H
Cypermethrin	✓	M	H	L	H
Dimethiote	✓	M	H	H	M
Profenofos	x[c]	M	H	H	H
Imidacloprid	✓[b]	M	H	H	M
Acetochlor	x[c,d]	H	M	M	M
Ametryn	x[d]	M	L	L	M
Atrazine	x[c,d]	M	M	L	M
Diuron	✓	M	L	M	L
Glyphosate	✓	M	M	M	M
MCPA	✓	M	L	M	M
MSMA	x[c,d]	H	M	L	M
S-metalochlor	✓	L	L	M	M

✓: yes; x: no; L: low, M: moderate, H: high (University of Hertfordshire Pesticides Properties Database).
[a] No specific ecotoxicology data is available for this product. Toxic to water birds, fish and bees (Abamectin MSDS, 2013).
[b] Approved with restrictions on certain flowering plants.
[c] Approved in the United States of America.
[d] Approved in Australia.

disposition. Monitoring of pests in time, space and varieties is routine.

3.3. Environmental pesticide load

The calculated EI per ha values for commonly used pesticides in sugarcane production in Malawi are indicated in Table 3. The range of a.i. EIQ values was 12.5–59.5 with lowest EIQ value for s-metalochlor and highest for profenothrin. EI per hectare for an active ingredient was a function of application rate. Agromectin and acetamiprid had the lowest EI per hectare (12.0 and 12.3–153.8) while dichlorvos and MCPA and MSMA had the highest EI per hectare values (7129.0, 5025.5, 4120.0 and 4044.4) respectively. Based on WHO (2009) classification of pesticides, 70% of the pesticides used by farmers were moderately hazardous while the rest were slightly hazardous (Table 3).

3.4. Effects of pesticides used on human health

Potential pesticide exposure pathways for farmers were pesticide storage, mixing, spraying and working in sprayed fields. Farmers preferred to store pesticides within the house (75%). The majority except of those with tertiary education lacked suitable personal protective equipment (PPE). Knee-length plastic boots and cotton overalls were the most widely used PPE (72%). All farmers recognized pesticides as poisons that can cause health problems. About 95% of them knew that pesticides could enter the human body through the skin, nose (53%) and mouth (42%). They knew that pesticides runoff (80%) and leaching (100%) lead to contamination of water wells. Food contamination through pesticide handling close to kitchens and spray droplets were recognized by over 80% of the farmers. All farmers in this study had knowledge of acute effects of pesticides. The most felt effects were skin irritation, 78%; headache, coughing and running nose (67%); skin rash (22%); fever, dizziness, chest pain and diarrhoea (11%). Vomiting and diarrhoea were mentioned only by female farmers ($F = 8.980$, $p = 0.005$).

Pesticides that no longer have regulatory approval or are under restricted use in the European Union (EU) were still approved by the Government of Malawi. Atrazine belongs to triazines and is an herbicide that does not have approval in the European Union (EU, 2009; PPDB, 2017). Ametryn is also a triazine herbicide that does not have regulatory approval in the EU due to its persistence in soil and water under certain conditions (PPDB, 2017). MSMA is not widely approved for use in the developed world due to its toxicity and persistence in soils (PPDB, 2017). Profenofos has high potential for bioaccumulation and is highly toxic to birds, fish and aquatic invertebrates (PPDB, 2017). Imidacloprid, acetamiprid, chlorpyrifos and cypermethrin are approved for restricted use in the EU since they are moderately to highly toxic to birds, honeybees and fish (Table 4).

4. Discussion

In this study, we report that pesticides are widely used to control weeds and arthropod pests infesting sugarcane cultivation in Malawi. We have also documented significant variation in pesticide application rates among smallholder farmers, a result consistent with previous findings elsewhere (Jallow et al., 2017; Schreinemachers et al., 2017). Only one of the 16 active ingredients reported in our study was extremely hazardous based on (WHO) classification. However, the majority are as moderately or slightly hazardous (PPDB, 2017). Although measures are in place to reduce human and environmental exposure to pesticides on the large estates and farms operated by farmer associations, smallholder farmers acting independently do not have the resources and capacity to minimize their exposure to pesticides.

We found that farmers relied on fellow farmers and extension workers for pesticide choice and handling. In addition, income did not influence farmers' pesticide choice. Our results partly agrees with the findings of Jallow et al. (2017). They found that other farmers were an important source of pesticide information for vegetable farmers in Kuwait. However, pesticide retailers significantly influenced Kuwaiti farmers' decisions to initiate pest control using pesticides, while pest occurrence was main determining factor for farmers in our study. The reason for these differences is that farmers in the study by Jallow et al. (2017) procured pesticides on a cash basis unlike the majority of smallholder farmers in our study, who got their pesticides on credit from the farmer association. In addition, only a few pesticides such as acetochlor, cypermethrin, acetamiprid and glyphosate are readily available from retailers in our study area. Farmers can access MSMA, MCPA and triazines only through the farmer association.

Herbicide cocktails (some with similar active ingredients and/mode of action) were used by more than a third of farmers in Nkhotakota. Since the crop is mostly rainfed in this area, many farmers were prompted to combine herbicides to combat high weed proliferation. In addition, some of these farmers grow cane in seasonal wetlands where difficult to control weed species such as *Cynodon* and *Cyperus* are the dominant species. However, over time this pesticides abuse (under- or over-dosing and using herbicide cocktails) could lead to development of herbicide resistance and other negative effects on the environment (El-Nahhal and Hamdona, 2017; Vencill et al., 2012).

We also found that plant and ratoon cane have different recommended rates of herbicides in Malawi. The likelihood of an illiterate farmer remembering the specific application rates for each growth stage are minimal. Even those who were able to read the pesticide label did not fully understand the information recorded on the label. As long as the herbicides are effective at the lower application rates, from a farmer's point of view, there is no compelling reason to adopt the recommended application rates. Disregarding pesticide label instructions increases the risk of pesticides poisoning, the development of herbicide resistance and environmental contamination.

We used the EIQ model to identify pesticides or pest management systems with a low environmental impact (Kromann et al., 2011; Eklo et al., 2003; Kovach et al., 1992). Pesticides with low EI per ha are considered to be more environmentally benign and can be integrated in IPM programs. Based on the EI, we recommend agromectin, acetamiprid, cypermethrin and dimethiote for insect pest control and a ban on dichlorvos. The use of some herbicides such as acetochlor and triazines need to be restricted to reduce negative impact on humans and other non-target organisms. However, the EI per hectare value does not provide actual quantitative meaning on the nature of impact of a pesticide on the environment (Peterson and Schleier, 2014; Dushoff et al., 1994). Hence, we obtained pesticide ecotoxicology data from the pesticides properties database of the University of Hertfordshire and WHO (2009) recommended classification of pesticides by hazards. Based on these two sources, we found that almost half of the pesticides reported in this study have potential to contaminate aquatic systems even at low concentrations (Olivier and Singels, 2015; Stoner and Eitzer, 2012). About 73% of the pesticides are also known to be highly toxic to honeybees, birds, fish and aquatic life (PPDB, 2017; Sanchez-Bayo and Goka, 2014; Ventura et al., 2008). The fact that there are no restriction on use of such pesticides is of great environmental concern. This is especially critical considering most of the rivers in the north and south of the country drain into Lake Malawi (GoM, 2010; Anonymous, undated). Rare species of birds in southern Africa and endemic fish species inhabit the shores and marshes of Lake Malawi, and the Dwangwa and Shire Rivers (Anonymous, undated; Avibase, 2003). It is importance therefore, to establish pesticide monitoring programs.

Four pesticides namely chlorpyrifos, acetochlor, MSMA and carbosulfan used by sugarcane farmers in Malawi are highly toxic to mammals (PPDB, 2017). In this study, we only documented acute symptoms of pesticide exposure. However, farmers are also at a greater risk of developing pesticide-related chronic diseases through continued pesticide use, poor pesticide handling practices, dietary exposure, and drinking and using pesticide-contaminated water (Van der Werf, 1996; Ouedraogo et al., 2014; Mostafalou and Abdollahi, 2013; Wang et al., 2011; Weichenthal et al., 2010). Farmers exposed to the organophosphates chlorpyrifos and profenofos are at greater risk of neurotoxication (PPDB, 2017). The chloroacetamide acetochlor is a mutagen, organ toxicant and affects the reproductive system. Atrazine is a carcinogen and may cause coma, respiratory collapse, gastric bleeding and renal failure (PPDB, 2017).

We find that all respondents interviewed knew the harmful effects of pesticides. They also had knowledge of pesticide exposure routes in humans, groundwater and food. However, they did not take precautionary steps to reduce their exposure or use recommended application rates. These findings are in line with similar studies done elsewhere (Jallow et al., 2017; Schreinemachers et al., 2017; Anang and Amikuzuno, 2015). Either smallholder farmers did not have full understanding of the health risks posed by pesticides or did not consider personal protective equipment a priority considering the majority could not understand the pesticide label and had minimal financial capacity. The decision by some sugarcane farmer associations to perform all pesticide related activities for the farmers is critical in reducing farmers' exposure to and environmental contamination by pesticides. Otherwise, associations may consider giving personal protective clothing and equipment as part of inputs given to farmers on credit.

Reducing pesticide exposure risk among sugarcane producers can be achieved by following IPM principles. The IPM package for weeds could include the following: a) preventative measures aimed at reducing infestation and spread of weeds such as field sanitation, weed control along field margins and trenches, and equipment disinfestation after each use. b) Enhancing the ability of the plant to outcompete weeds. This can be achieved through varietal selection, observing seeding rates, row spacing, and fertilizer rates and placement. c) Herbicide rotations and application at recommended application rates. This is a very crucial aspect considering that farmers did not follow the approved application rates.

Some key pests, e.g. aphids can be managed by using fungal entomopathogens alone or in combination with insecticides (Wraight et al., 2016; Akbari et al., 2014; Tefera and Pringle, 2004). Kasambala Donga et al. (unpublished) are documenting the occurrence of and characterizing fungal entomopathogens in sugarcane cropping systems in Chikwawa. They are also evaluating the potential efficacy of *Beauveria bassiana* (Hypocreales: Ascomycota) foliar sprays against aboveground arthropod pests of sugarcane under field conditions at the Nchalo Estate.

5. Conclusion and recommendations

Our results indicate the environmental and health risks associated with pesticides currently used for controlling weeds and arthropod pests infesting sugarcane in Malawi. We show that there is a need for training both farmers and extension personnel in sugarcane production. There is a need for pesticide awareness campaigns targeting farmers, agro-dealers, farmer associations and extension workers. We greatly recommend providing pesticide labels in vernacular languages. There is also a need to conduct further studies to determine which pesticides applied in sugarcane fields are leaching and contaminating the environment. One important research topic is examining pesticide residue levels in groundwater wells used by communities surrounding sugarcane estates. It is also important to track pesticide residues in non-target organisms such as birds nesting in grasses and reeds, and fish in water bodies draining through sugarcane fields.

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