POTENTIAL ENVIRONMENTAL IMPACTS OF PESTICIDES USE IN THE VEGETABLE SUB-SECTOR IN KENYA

Macharia, I.[1], Mithöfer, D.[2] and Waibel, H.[1]
[1]Leibniz University of Hanover, Faculty of Economics and Business Administration, Königsworther Platz 1, 30167 Hannover, Germany
[2]International Centre of Insect Physiology and Ecology, P. O. Box 30772, Nairobi, Kenya
Correspondence e-mail addresses: macharia@ifgb.uni-hannover.de, waibel@ifgb.uni-hannover.de

ABSTRACT

Systematic studies on negative pesticide impacts are scarce in developing countries including Kenya. This paper reports the current pesticide use and associated impacts in Kenya. As a proxy for assessing the impact, the Environmental Impact Quotient (EIQ) model was applied. Results showed that in vegetable production 62 products, comprising of 36 active ingredients are in use. Approximately 263 tons of pesticides were applied at an average rate of 0.82 kg/ha. About 35% of the volumes belong to the organophosphates, 25% carbamates, 22% pyrethroids, 7% tetranortriterpenoids, and 7% inorganics. Of the pesticides, 8% were classified as highly hazardous compounds by the World Health Organization, 25% as carcinogens, while 43% are said to be possible carcinogens. Approximately 60% of the pesticides quantities were indicated to be bad actor chemicals, 64% to be ground water contaminants, and 47% very harmful to beneficial insects. Calculated mean EIQ-values were 22, 6 and 82 for farm workers, consumers and the environment, respectively, with an overall average of 37. The present results indicate that the sub-sector potentially has environmental pesticide negative impacts. The EIQ field use rating, which is based on the percent active ingredient and application rate clearly demonstrate that some pesticides that pose fairly low threat can be chosen to manage pests.

Key words: Environmental Impact Quotient, Non-target organisms, Pesticides, Pest management, Vegetables

INTRODUCTION

Concerns due to risks of non-target impacts of pesticides is increasing globally as shown by increasingly more stringent standards on pesticide residue levels. Pesticides cause: acute and chronic human health effects, contamination of atmospheric, ground and surface water (Howard et al., 1991; Mullen, 1995; Matthews, 2006). Different pesticides have been implicated in chronic neurotoxicity, endocrine disruption, immune impacts, genotoxicity, mutagenicity and carcinogenesis (Maroni and Fait, 1993; Abou-Donia, 2003; Galloway and Handy, 2003; Choi et al., 2004). Non-target organisms such as plants, earthworms, termites, ant colonies, snakes, birds, toads, lizards and other amphibians have been affected negatively by pesticide use (Beyer and Gish, 1980; Hall and Henry, 1992; Driver, 1994; Campbell and Campbell, 2001; Mosleh et al., 2003; Larson et al., 2005). Due to growing concerns, assessment of pesticide impacts is inevitable. Generally, determination of the environmental impact of pesticides depends on several factors such as pesticide active ingredient, dose rate, application frequency and method, environmental conditions (weather, soil type, geological formation), and site characteristics (available surface water resources, presence of biological species) (Reus et al., 1999).

In Kenya, use of pesticides has been promoted to expand agricultural production and increase productivity. In 2005, approximately 7,047 metric tons of pesticides, valued US$54 million were imported, with insecticides accounting for about 40% volume and 50% total cost (Table 1) (PCPB, 2005). Incidentally, Kenya is the leading producer of a natural pesticide, pyrethrin, which is a broad-spectrum insecticide made from dried flowers of pyrethrum (*Chrysanthemum cinerariaefolium*). However, 95% of the crude pyrethrin is exported to more environmentally conscious developed countries, where it earns a premium price, leaving Kenya to import the cheaper toxic synthetic pesticides.

Table 1: Volume, value and percentage of pesticides imported in 2005

Pesticide group	Quantity (tons)	Share (%)	Value (million US$)	Share (%)
Insecticides	2881	41	28	53
Fungicides	2031	29	15	28
Herbicides	1538	22	9	16
Others	597	8	2	3
Total	7047	100	54	100

Source: Pest Control Products Board (2005)

Currently, systematic studies on negative impacts of pesticide use are scarce in developing countries. The present paper provides an overview of current pesticide use and associated impacts. Environmental Impact Quotient (EIQ) model was applied to assess the impacts. There are other environmental impact assessment models, including Pesticide Environmental Impact Indicator (Ipest) (Van der Werf and Zimmer, 1998), Environmental

Yardstick (EYP) (Reus and Leendertse, 2000), SYNOPS (Gutsche and Rossberg, 1997), Environmental Performance Indicator of Pesticides (p-EMA) (Lewis and Bardon, 1998; Brown et al., 2003), Environmental Potential Risk Indicator for Pesticides (EPRIP) (Trevisan et al., 2000), System for Predicting the Environmental Impact of Pesticides (SyPEP) (Beernaerts and Pussemier, 1997), and Pesticide Environmental Risk Indicator (PERI) (Nilsson, 1999). The information included in these indicator models varies widely and depends on the developers. However, they all provide valuable information in comparison to costly evaluation methods of sampling and monitoring of pesticides. EIQ system model was chosen for this study because of its structural simplicity, general applicability, ease of use and being the choice model by many scholars (Fernandez-Cornejo, 1998; Edwards Jones and Howells, 2001; Ziegler et al., 2002; Bues et al., 2003; Lan et al., 2003; Brimner et al., 2005),

MATERIALS AND METHODS

EIQ Model

The EIQ system model was developed by Kovach et al. (1992), to support environmentally sound pesticide choices in assessing compatibility of pesticides with integrated pest management (IPM) practices. To estimate the hazard to farm workers, consumers and ecological factors, the EIQ utilizes toxicological data. The toxicological data are normalized to a three point scale of 1, 3 or 5 in accordance with their hazard (1 being the lowest hazard, 5 the highest). The potential risks for each pesticide is based on measures of toxicity such as the LD_{50} (dose at which 50% of the treatment group dies within the specified time period) or LC_{50} (concentration at which 50% of the treatment group dies within the specified time period), and potential exposure such as the half-life, runoff or leaching potential. The farm worker category includes potential effects to applicators and fieldworkers; the consumer category includes the potential effects of residues on the consumer and ground water contamination. Ground water effects are included in the consumer component because it is more of a human health issue (drinking contaminated water) than a wildlife issue. The ecological category includes the potential effects on aquatic organisms, bees, birds and beneficial arthropods. The formula for determining the EIQ value of an individual pesticide (EIQpesticide) is given by the Equation: EIQpesticide = (EIQfarmworker + EIQconsumer+ EIQenvironmental)/3. Where: EIQfarmworker = C(DT*5)+(DT*P), EIQconsumer = (C*(S+P)/2)*SY)+(L), EIQenvironmental = (F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5). The symbols are described in Table 2.

Table 2. Rating system for variables in EIQ model (Kovach et al., 1992; Levitan, 1997)

Variable	Symbol	Rating scores		
		1	3	5
Chronic toxicity	C	little or none	Probable	Evidence
Acute dermal toxicity (LD50 for rabbits/rats mg/kg)	DT	>2000	200–2000	0–200
Bird toxicity (8 day LC50)	D	>1000 ppm	100–1000 ppm	1–100 ppm
Lethality to honey bees (at field doses)	Z	relatively non toxic	moderately toxic	highly toxic
Beneficial arthropod toxicity	B	low	moderate	severe
Fish toxicity (96 hr LC50)	F	>10 ppm	1–10 ppm	<1 ppm
Soil residue half-life	S	<30 days	30–100 days	>100 days
Plant surface residue half-life	P	1–2 weeks	2–4 weeks	> 4 weeks
Mode of action (systemicity)	SY	non-systemic	systemic	
Leaching potential	L	small	medium	large
Surface loss potential	R	small	medium	large

The EIQ system relies on published toxicology and environmental fate data from several sources such as EXTOXNET (Hotchkiss et al., 1989), SELCTV database (Theiling and Croft, 1988) for impacts on beneficial insects, and GLEAMS for estimating ground water mobility of individual pesticides (Leonard et al., 1987). An EIQ field use rating is calculated as the EIQ value for individual pesticides, multiplied by the percentage active ingredient multiplied by the total amount of pesticides used (kg/ha).

Although the EIQ can yield fruitful information, it has limitations as a measure of pesticide risk (Dushoff et al., 1994; Levitan et al., 1995). The first limitation is the scoring system. In calculating the EIQ, the toxicity of pesticides and potential exposure are scored on a 1, 3, 5 scale, which reduces sensitivity of the EIQ to differences among pesticides. The second limitation is the difficulty of defining exposure. The EIQ measures potential exposure as half-life and run-off potential. However, timing of application may be as important as half-life in determining exposure to farm workers or other species. Soil type and temperature may influence pesticide adsorption, solubility, and half-life (Dushoff et al., 1994), the major components in the calculating leaching and runoff potential (Kovach et al., 1992). Also, toxicity of a pesticide to species may vary widely depending on factors such as size and stage of development.

Data Sources

The yearly horticultural reports from the Ministry of Agriculture (MoA) were consulted for vegetable area and production statistics. Annual reports from the PCPB provided the pesticide import volumes. The study primarily used results of 839 farmer interviews from two surveys conducted by ICIPE in 2005. These were the diamondback moth biological control impact assessment survey (DBMI) and Global Good Agricultural Practices (Global-GAP, formerly known as the European Union Retailers Produce Working Group for Good Agricultural Practices (EurepGAP)), assessment survey conducted in seven major vegetable producing districts in Central and Eastern provinces of Kenya (Nyeri North, Kirinyaga, Muranga, Kiambu, Nyandarua, Meru Central and Makueni). In both surveys, a multi-stage sampling procedure was employed to select districts, sub-locations and farmers. First, districts were purposely sampled according to level of vegetable production and location. Farmers were then sampled proportional to the size. Lists of farmers compiled by extension workers at sub-location level served as sampling frame from which 295 farmers for DBMI and 544 farmers for Global-GAP were randomly sampled. Sampled farmers were then monitored in one cropping season and trained in record keeping of their production activities. Trained field research assistants visited them to check the records and transfer information to the survey questionnaire. Information on the type of crops, type and application rates of pesticides was recorded.

For this study, percentage of farmers reporting use of each of the pesticide for each of the six major vegetable (kales, tomatoes, cabbages, French beans, onions and garden peas) were multiplied with the total area under that vegetable as stated in annual reports of the MOA (2005) to arrive at the area treated. Summation of all areas for each vegetable treated resulted to area treated with that product. The rate of the formulated product per hectare was multiplied with the area treated to arrive at the approximate amount of pesticide used. Asian vegetables were also grown, but due to the small number of farmers who grow them, they were dropped from the analysis. A list of all pesticides applied to each of the six major vegetables and their application rates was obtained from the surveys. Recommended dosages for pesticide application were obtained from pesticide labels and cross-referenced with those conventionally put in company catalogue. EIQ values for each active ingredient of a pesticide used were obtained from internet sites e.g., http://www.nysipm.cornell.edu/publications/EIQ_values03.pdf, or calculated based on the chemical's toxicological and physical properties using the procedure outlined by Kovach et al. (1992). Where major data gaps existed, the mean values of known pesticides within the same chemical group were used to calculate a surrogate rating.

RESULTS AND DISCUSSION

Kales occupied a higher production area than other vegetables grown (Table 3). Cabbage and kale production almost exclusively target domestic markets hence their export share is less than 1%. French beans are the major export vegetable and accounted for 61% of the volume of vegetables exported in 2005 (MOA, 2005). Plot size for the vegetables fell between 0.004 ha and 2.32 ha with an average of 0.14 ha per farmer; cabbage occupied the biggest area of 0.22 ha (Table 3). The farms varied in size from 0.02 to 11.23 ha and comprised five general cropping systems: cereals, legumes, field crops, dairy fodder crops, and intensive vegetable farming. Nonetheless, the mean share of vegetable production area to the total landholding (1.15 ±0.04 ha) was on average (12%), considering the five major cropping systems.

Table 3. Major vegetable grown in the subsector

Vegetable	n	Area (ha/ farmer)[a]	Total area (ha)[b]	Production (tons)[b]	Value (million US$)[b]	Yield (t/ha)[c]
Kales	52	0.07 (0.01)	26,818	315,159	21	12
Tomatoes	30	0.12 (0.02)	20,743	337,447	44	16
Cabbages	295	0.22 (0.02)	20,527	529,003	59	26
French beans	226	0.10 (0.01)	7,004	62,189	17	9
Onions	7	0.07 (0.02)	6,395	68,86	19	11
Garden peas	68	0.09 (0.01)	5,313	22,798	6	4
Total	839	0.14[d] (0.01)	86,800	1,266,596	166	13[d]

Source: [a] = own data; [b] = MoA (2005); n = number of surveyed farmers producing the crops; Figures in brackets are standard errors.

A total of 62 pesticide products, comprising of 36 active ingredients, were in use in the subsector. Approximately 52% were insecticides, 41% fungicides, 5% acaricides, and 2% were herbicide. Based on the survey information and the reported vegetable hectare in the MoA reports (MoA, 2005), approximately 263 tons of pesticide were used, representing only 5% of the total amount of pesticide imported in 2005 (PCPB, 2005). Dimethoate was the most extensively used pesticide with 79 tons applied to over 48% of the total vegetable crops area, followed by Dithane M45 (55 tons applied on 28% area), and Karate (27 tons applied on 24% area). Only 4 tons of the commercial bioinsecticides based on the bacterium *Bacillus thuringiensis* were used (Table 4). In general, application rate was in the range of 0.02 to 3.51 kg/ha, with an average of 0.82 kg/ha (Table 4). In general, 35% of the pesticides used belonged to organophosphates, 25% to carbamates, 22% to pyrethroids, 7% to tetranortriterpenoids, 7% to inorganics, and the rest were less than 1%. The WHO has classified 57% by volume of pesticides applied as moderately hazardous, 8% as highly hazardous compounds, 25% as carcinogens, and 43% as possible carcinogens.

Table 4: EIQ values for the 25 commonly used pesticides with rate of application and estimated volumes applied (n=839)

Active ingredient	Trade name	Chemical family	EIQ F	EIQ C	EIQ E	EIQ total	Rate (kg/ha)	Field use	% farmers using	Vol. (kg)
Insecticides (32)										
azadirachtin	Achook	Tetranortriterpenoids	6	2	30	13	1.6	8	6	18882
B. thuringiensis	Thuricide H P	Microbial	6	2	16	8	1.3	4	2	2293
B. thuringiensis	Dipel	Microbial	6	2	16	8	1.0	3	5	1567
chlorpyriphos	Dursban 4EC	Organophosphate	18	4	109	44	0.6	26	1	1064
cypermethrin	Bulldock 25EC	Pyrethroid	9	4	69	27	2.4	26	10	20678
cypermethrin	Cyclone 505EC	Pyrethroid	9	4	69	27	0.8	108	6	3643
deltamethrin	Farm-X	Pyrethroid	6	3	68	26	0.4	4	13	2993
deltamethrin	Decis 25EC	Pyrethroid	6	3	68	26	0.4	3	12	1724
deltamethrin	Atom 2.5EC	Pyrethroid	6	3	68	26	0.9	2	1	933
dimethoate	Dimeton 40EC	Organophosphate	72	9	141	74	1.9	56	37	78744
dimethoate	Danadim 40EC	Organophosphate	72	9	141	74	1.1	33	3	6158
lambda cyhalothrin	Karate 2.5WG	Pyrethroid	21	3	106	44	1.1	16	27	26939
lambda cyhalothrin	Tata Alfa 10EC	Pyrethroid	21	3	106	44	0.3	5	4	1012
methomyl	Lannate 90	Carbamates	6	11	75	31	0.6	17	3	822
methomyl	Agrinate	Carbamates	6	11	75	31	0.9	11	1	803
profenofos/ cypermethrin	Polytrin 440EC	Organophosphate/ pyrethriod	9	4	69	27	1.2	143	1	2702
Fungicides (26)										
azoxystrobin	Ortiva	Strobilurin	6	5	35	15	0.9	5	3	663
famoxadone/ cymoxanil	Equation Pro	Oxazolidinedione	9	3	24	12	1.3	6	2	601

Table 4: (Continued)

Active ingredient	Trade name	Chemical family	EIQ F	EIQ C	EIQ E	EIQ total	Rate (kg/ha)	Field use	% farmers using	Vol. (kg)
copper hydroxide	Copper	Inorganic	12	5	83	33	0.5	7	3	1243
copper sulfate	Copper fungicide	Inorganic	81	15	48	48	1.2	23	3	4023
cymoxanil/ propineb	Milraz 76WP	Cyanoacetamide-oxime	6	6	14	9	1.0	4	1	620
mancozeb	Dithane M45	Carbamates	12	3	29	15	2.6	20	14	54692
mancozeb	Oshothane	Carbamates	12	3	29	15	1.4	8	1	3477
mancozeb	Penncozeb 80WP	Carbamates	12	3	29	15	1.2	14	1	3140
profenofos	Selecron 720EC	Organophosphate	7	2	121	43	0.6	186	1	859
Others*			24.1	7.5	87.0	39.5	0.6	22.8	22.1	22752
Average (62)			21.7	6.2	81.9	36.7	0.8	27.4		263027#
Standard error			3.8	0.6	6.7	2.8	0.1	4.8		1634.0
Median			10.0	5.0	72.0	32.0	1.0	16.5		620.0
Minimum			6.0	2.0	14.0	8.0	0.0	2.2		1.0
Maximum			173	31	240	89	4	186		78744

NB: Figures in brackets give the total number of pesticides found. EIQ F= farmer worker component. EIQ C= consumers component. EIQ E= environmental component. #Sum of total amount used during the crop season. *Includes the 3 acaricides and the 1 herbicide

Approximately 60% of the pesticides quantities are indicated by Pesticide Action Network North America (PAN) as bad actor chemicals (i.e. chemicals that are highly acutely toxic, cholinesterase inhibitors, known/probable carcinogens, known groundwater pollutants, or known reproductive or developmental toxicants), 64% as ground water contaminants and 47% as very harmful to beneficial insects. One of the active ingredients found (paraquat) is classified by PAN as dirty dozen because it is highly toxic to animals and humans and is blamed for causing severe, acute and long-term health problems and is banned in most countries. About 7% of the pesticides are listed as extremely or highly hazardous (class Ia and Ib) and 36% as moderately hazardous by the WHO (2006).

The calculated EIQ values ranged from 8 to 89, with an average of 37 (Table 4). *Bacillus thuringiensis* had the lowest, while the highest was for permethrin (not in the table due to low volumes estimated, 97 kg). Mean EIQ values for farm workers, consumers and environmental component were 22, 6 and 82, respectively (Table 4). This result indicates that the farm worker component is 3.5 times greater than the consumer component, and environmental factors are rated 3.8 times greater than the farm workers component and 13.2 times higher than the consumers component, revealing probability of higher impact on the environmental component. Basing the calculation to the Mazlan and Mumford (2005) EIQ classification rule, values for all the pesticides showed that 27%, 38% and 34% were rated as low (EIQ = 0 to 20), medium (EIQ = 21 to 40) and high (EIQ ≥ 41), respectively. The field-use EIQ rating ranged from 1 to 186, being lowest for Methomex (methomyl) and highest for Selecron 720 EC (profenofos). The number for Selecron was higher primarily due to the high percentage active ingredient formulation. Other pesticides with lower values below the median in increasing order included: insecticide (Polytrin C200 EC, Atom 2.5 EC, Tristar 70 wsp, Decis 25 EC, Dipel, Thuricide HP, Farm-X, Topsin, Tata Alfa 10 EC, Malathion TK, Metasystox, Achook, Diazinon 60 EC, Talstar, Ambush 25 DC, Agrinate, Alfix, Brigade 25 EC, Karate 2.5 WG), fungicides (Sancosen, Milraz 76 WP, Funguran WP, Ortiva, Equation Pro, Folicur, Copper, Daconil W75, Oshothane, Penncozeb 80 WP, Cosavet DF).

According to the EIQ field use rating values, comparison of pesticides can be done and pesticides with the least detrimental effects can be chosen. For examples, both Methomex and Karate 2.5 WG are used for the management of aphids and thrips on beans. However, the impact of Methomex is quite low when compared to Karate. This fact can guide farmers to choose less harmful pesticides that reduce the environmental impact.

The pattern of pesticide use differed significantly among the vegetables. The insecticides and fungicides applied in French beans were much higher compared to kales. However, the application rates for specific pesticides were significantly higher for kales than other crops; e.g., Bulldock 25EC and Dithane M45. Differences were even most apparent when individual insecticides were consolidated by chemical family. Only one herbicide (Gramoxane) was being applied on peas, while the three acaricides (Dynamec, Omite and Vapcothion) were utilized on specific vegetables. Omite was purposely used on tomatoes probably to control the notorious red spider mite *Tetranychus evansi*, which is the major constraint in tomato production in Kenya, and Vapcothion to control the same mite on peas. Dynamec was applied across the board (Figure 1).

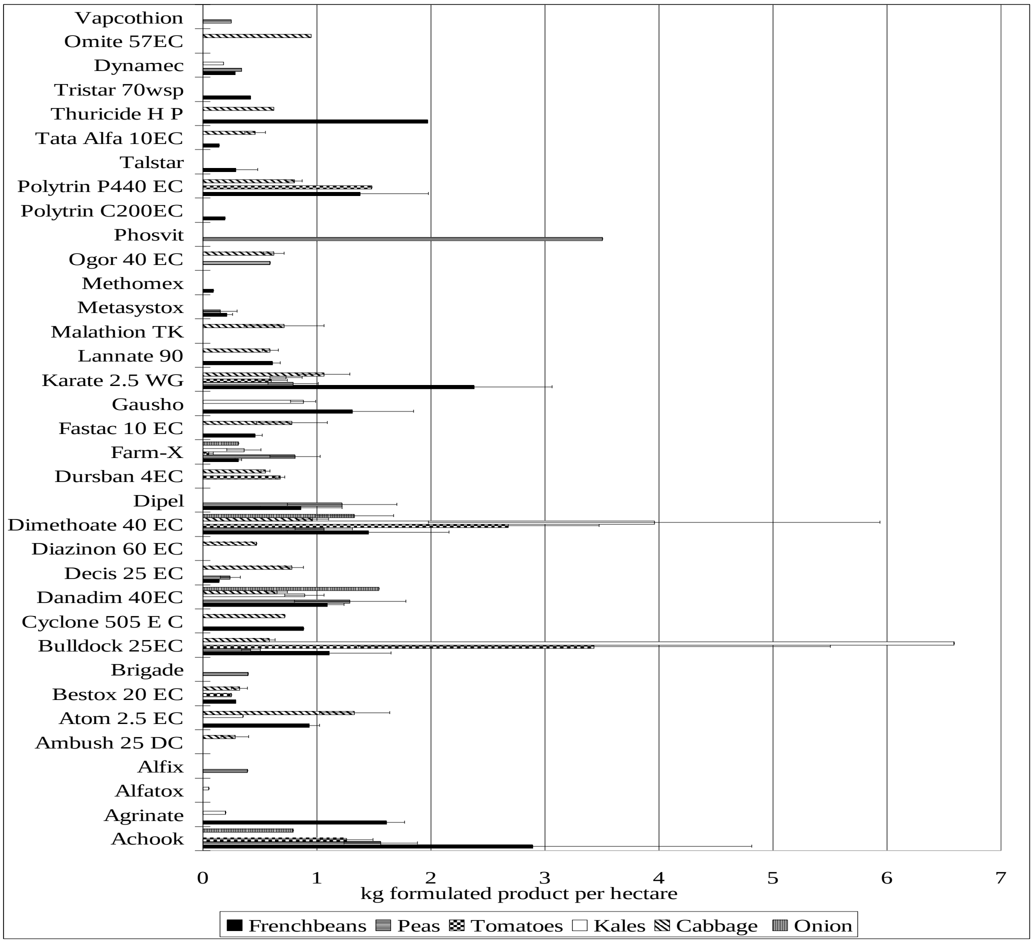

Figure 1. Insecticides and acaricides (Dynamec, Omite and Vapcothion) used in the six major vegetables (n=839)

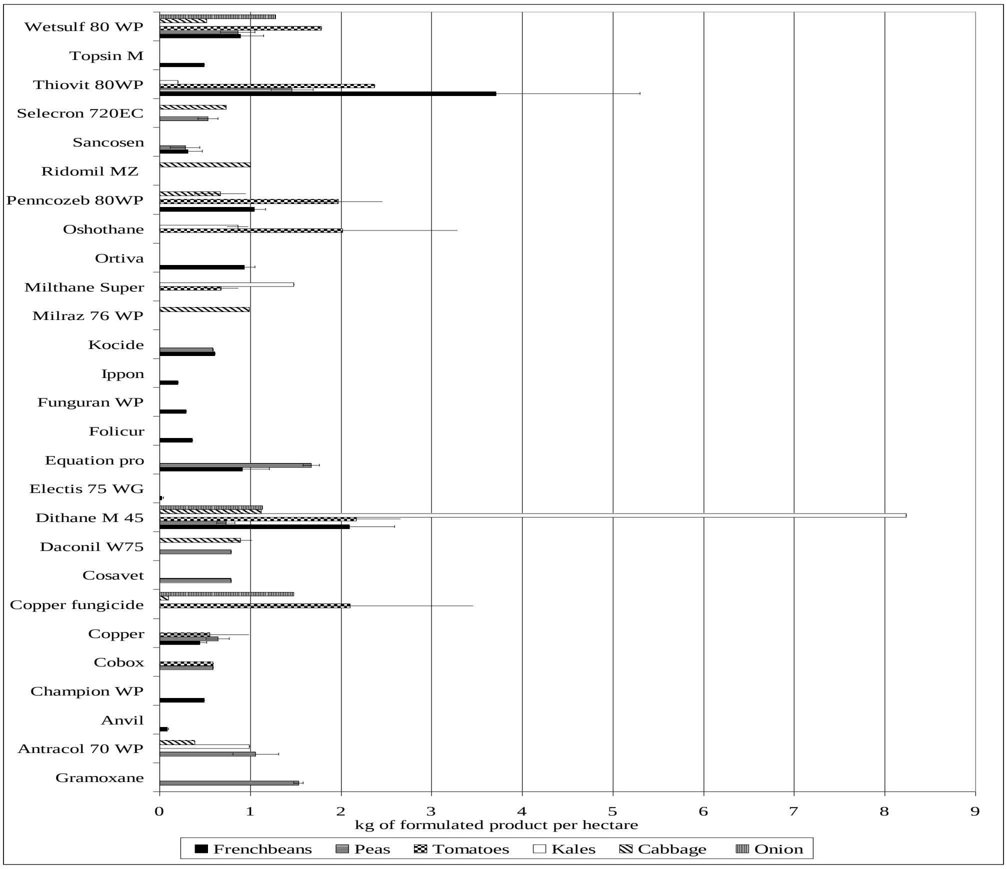

Figure 2. Fungicides and herbicide (Gramoxane) used in the six major vegetables (n=839)

CONCLUSIONS

The present study reveals that pesticide use in production of vegetables is quite high, with 62 formulations from 36 active ingredients. The application rate of 0.82 kg/ha is fairly low compared to other countries in Latin America (7.17 kg/ha) and Asia (3.12 kg/ha) (Repetto and Baliga, 1996). However, some pesticides are extremely harmful even when used at low rates. The EIQ values calculated indicate that the sub-sector potentially has pesticide negative environmental impacts. The EIQ field-use rating clearly demonstrates that some pesticides that pose fairly low threat can be chosen. Therefore, a combination of pesticide regulatory policies to control use of highly toxic pesticides and effective programmes to raise farmers' awareness of pesticides that pose little threat would help safeguard the environment and human health. Although the present study was conducted in the vegetable sub-sector only, the results may probably extent to the general horticulture sector.

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