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Hubert Bon, Joël Huat, Laurent Parrot, Antonio Sinzogan, Thibaud Martin, Eric Malézieux, Jean-François Vayssières

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REVIEW ARTICLE

Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review

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Abstract Chemical control has highly expanded over the last 30 years in sub-Saharan Africa to reduce bio-aggressors on all crops. Pest management of fruits and vegetables by small farmers in sub-Saharan Africa have developed anarchically in a fuzzy regulation framework. Pesticide toxicity and excessive application are often criticized both by farmers and consumers. Here, we review pesticide management in sub-Saharan Africa over the past 30 years. We then propose options to improve and reduce pesticide application, in order to decrease environmental and human hazards. The major points are as follows: (1) global changes in sub-Saharan Africa such as urbanization modify farmer practices and crop losses. (2) Pesticides are more and more used by small farmers in an unsustainable way. (3) The risk of pesticide application for human health and environment is poorly known. (4) We propose options to reduce pesticide application based upon integrated pest management (IPM) and agroecology. Moreover, IPM increases farmer economy, thus decreasing poverty.

H. de Bon (✉) · J. Huat · L. Parrot · T. Martin · E. Malézieux · J.-F. Vayssières
CIRAD, UPR HortSys, F-34398 Montpellier Cedex 5, France
e-mail: hubert.de_bon@cirad.fr

J. Huat
Africa Rice Center, 01 BP 2031, Cotonou, Benin

A. Sinzogan
Faculté des Sciences Agronomiques, Université d 'Abomey Calavi, 03 BP 2819, Cotonou, Bénin

T. Martin
Icipe, African Insect Science for Food and Health, PO Box 30772-00100, Nairobi, Kenya

J.-F. Vayssières
International Institute of Tropical Agriculture, 08 BP 0932, Cotonou, Benin

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Contents

1 Introduction

Crop protection is an essential component of fruit and vegetable production, especially in tropical areas. Various methods have been developed both in temperate and tropical countries to control pests and diseases: resistant cultivars, biological control, chemical control, cultural practices, and integrated pest management (IPM). However, despite existing alternative practices, the use of chemical pesticides has grown dramatically particularly since the 1970s all over the world and Africa is no exception to the trend (Abate et al. 2000; Parrot et al. 2008a).

The word pesticide used in the paper is a shortcut for the official name in the European commission which is “plant protection product”. Plant protection product is any substance and preparation of one or more substances, put up in the form in which they are supplied to the user, intended to protect or preserve plants or plant products, influence life process of plants, destroy undesired plants, or check or prevent undesired growth of plants (Directive 94/414/EEC). The word pesticide includes chemical herbicides, fungicides, insecticides, nematicides, and acaricides to control, respectively, weeds, fungus, insects, nematodes, and mites.

In sub-Saharan Africa, pesticides are mainly used in cash crop production either for export (cotton, rice, coffee, cocoa, mangoes) or for the local market (vegetables, rice, and various fruits including mangoes). The main production of vegetables in Africa are as follows: tomato 17.2 MT, dry onion 9.4 MT, watermelon 5.3 MT, and cabbages and other brassicacae 2.4 MT. We are focusing on some important African production of fruits as 18 MT of citrus, 4.8 MT of mangoes, and 3.1 MT of dates in 2011 (FAO 2013). Among fruit crops, bananas and pineapples, which are more industrial ones, are not included in this review. Maintaining high levels of productivity and profitability while reducing environmental, economic, and sanitary costs linked with pesticide use has now become a major challenge for agriculture and horticulture worldwide. The result of a poor pesticide management is often environmental contamination and severe human health problems (Vayssières 2007; Williamson et al. 2008; Ahouangninou et al. 2011; Yadouleton et al. 2011). Moreover, as insecticides used in agriculture belong mainly to the same family (pyrethroid and organophosphorus) as those used in public health, the selected resistant mosquitoes endanger vector control strategies (Yadouleton et al. 2011). Many smallholder farmers widely use chemical inputs including pesticides as a strategy for poverty alleviation and food security (Fig. 1).

It is argued that without pesticides, there would be greater crop losses and shortfalls in food supplies (Snelder et al. 2008). This situation reflects the conflict between intensive use of synthetic pesticides by small farmers and both the risk of environmental degradation and sanitary risks for farmers and consumers. Besides studies to enhance the beneficial effects of pesticides (Cooper and Dobson 2007), several authors have shown negative effects on environmental quality and human health as well as on horticultural crops (Roberts 1987; Kidd et al. 2001; Ntow et al. 2006; Sinzogan et al. 2008; Sumberg and Okali 2006 ; Ajayi et al. 2011).

There are major challenges in sub-Saharan Africa, where poverty, low training, and susceptibility to pests contribute to major risks. The goal of this review is to synthetize existing literature on the current pesticide use by small horticultural growers in sub-Saharan Africa and some effective environmental

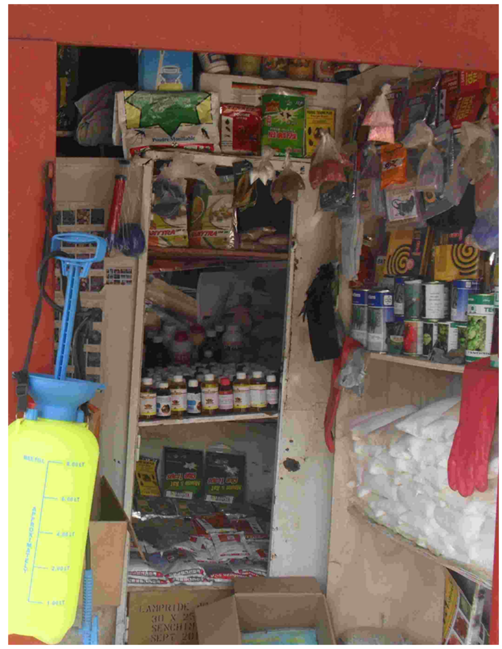

Fig. 1 Shop seller of agricultural supplies (pesticides, seeds, knapsack sprayer) in a peri-urban vegetable production area in Dakar (H. de Bon)

friendly alternative methods. We present (a) the socio-economic context of horticultural crops in these countries and the outline of losses in the vegetables and fruit sector due to pests and diseases, then (b) the current pesticide use by vegetables and fruit small growers (c) the risks linked to their practices, and (d) alternative crop protection strategies for reducing pesticides use.

2 Global changes in sub-Saharan Africa and crop losses

The number of farmers in West Africa is expected to rise from 100 million farmers in 2000 to about 150 million by 2020 (Cour 2001). In sub-Saharan Africa, about 330 million of young people will join the labor market from 2010 to 2025. About 40 % of those young people will initially be located in the rural areas. These numbers give an idea of the magnitude of the challenges for agriculture. Two reasons may explain why in Sub-Saharan Africa, we can expect the rise of fruit and vegetable production in the future and the concerns for pesticide issues: the urbanization process and the prevalence of the informal sector. These two factors will not only increase the size of the markets for pesticides but also increase the risks inherent in pesticide misuse.

2.1 Urbanization

The urbanization process increases food demand in cities, changes dietary patterns towards fruits and vegetable consumption, and makes fruits and vegetable production more competitive in the urban and peri-urban areas than staple crops (FAO 2012). As a result, the urbanization process should contribute to increasing the share of domestic fruits and vegetables production among farmers and the intensification process of agriculture. In fact, by 2030, it is expected that 50 % of the population in Africa will live in cities (United Nations 2006) but farming provides food security and income to more than 50 % of this same population. In Cameroon and Senegal, for example, respectively, 70 and 53 % of the population is expected to live in cities while the agricultural sector still provides income for 60 % their population (United Nations 2006; MINADER 2006; ANSD 2007). A large number of farmers will be involved in fruit and vegetable production for commercial or subsistence purposes, and farming will be conducted in urban or peri-urban areas, raising concerns for the environment and human health.

2.2 The informal sector

The prevalence of the informal sector impacts the behavior of farmers and the commodity chains around pesticides. The informal sector includes underground production (activities that are productive and legal, but are deliberately concealed from the public authorities to avoid payment of taxes or complying with regulations), illegal production (productive activities that generate goods and services forbidden by law or that are unlawful when carried out by unauthorized producers), and informal sector production (productive activities conducted by unincorporated enterprises in the household sector that are unregistered and/or are less than a specified size in terms of employment and that have some market production). From this definition (OECD 2002), we can see the implications for farmers and the stakeholders involved in the pesticide commodity chain. The average size of the shadow economy as a proportion of the official gross domestic product (GDP) in 1999–2000 in developing countries was 41 %, in transition countries 38 %, and in OECD (Organization for Economic Cooperation and Development) countries 17 % (Schneider and Enste 2000).

The informal sector affects the population in general due to the precariousness of the living conditions. For example, about 90 and 75 %, respectively, of the workers in Cameroon and Senegal do not have a formal contract (DPS 2004; INS 2005). This situation makes farming and immediate returns a necessity. Most African farmers are subsistence farmers with less than 1 ha of land, and they adopt pesticides in various contexts, from land owners endowed with secure property rights who invest in the long run to migrants who speculate in the short run, along with non-farm activities. Moreover, pest outbreaks may occur due to shortened fallow periods, in a context of land use intensification. To cope with this risk due to pests, farmers may adopt high-yielding varieties or use agrochemical inputs (Abate et al. 2000). The situation is aggravated by the lack of funding for extension services. As a result, the highly diverse situations and the large number of subsistence farmers increase the risk and magnitude of pesticide malpractices.

The informal sector makes it difficult to assess the situation of the commodity chains around pesticides on a global scale and to monitor suppliers and farmers. In Ethiopia for instance, obsolete stockpiles account for approximately 1,500 t (Haylamicheal and Dalvie 2009). The lack of data makes it difficult to draw up any estimates of the size of obsolete stockpiles of pesticides (Matthews et al. 2003), as well as any estimates of long-term and induced costs for pollution and health (Wilson and Tisdell 2001), and even any estimated running costs measurements (Ngowi et al. 2007).

2.3 Pest-induced food crop losses

The prevention of pest-induced food crop losses at pre-and post-harvest stages is an integral part of the Millennium Development Goal to ensure food security and poverty reduction. In 2010, for example, losses attributed to pathogens, insects, virus, and weeds in six major crops (rice, wheat, maize, potatoes, soybean, and cotton seeds) amounted to US$121.08, 35.02, 16.16, and 14.79 billion in Asia, America, Africa, and Europe, respectively (Table 1).

Pest and disease control is a permanent challenge for fruit and vegetable farmers in Africa. The reduction of food supply due to pests can lead to malnutrition, inadequate access to purchased food, medical care, and education due to a drastic reduction of incomes (Wilson and Tisdell 2001; Williamson et al. 2008). In addition, studies show that climate change will induce in the next 50 years a higher pressure on yields in most conditions in Africa due to higher pest damage, increased rainfall availability, and temperature rises (Jaramillo et al. 2011). In tropical areas, the lack of cold season and the presence of food for pests throughout the year make fruits and vegetables highly vulnerable to increased pest infestations from non-agricultural land.

Losses have been estimated by some authors for some crops, pest, and disease (Table 2). They vary from 1 to

Table 1 Estimated losses for six crops (rice, wheat, maize, potatoes, soybean, cotton seeds) in 2010 (from data FAO 2013; Oerke and Dehne 2004; Oerke 2006)

Region	Losses due to pest (US$ billion)				
	Weeds	Insects	Pathogens	Virus	Total
Africa	4.93	4.91	4.73	1.60	16.17
America	11.31	11.13	9.23	3.35	35.02
Asia	34.82	38.88	37.78	9.60	121.08
Europe	3.20	4.83	4.47	2.29	14.79

Table 2 Estimated losses for some fruits and vegetable crops for some viruses, insect, bacteria, and fungus

Fruits and vegetables	Pests and diseases	Estimated losses (%)	Location	References
Bean	Bean yellow dwarf virus	85–92	South Africa	Varma and Malathi 2003
Bean	*Ophiomyia spp.*	8–100	Eastern and southern Africa	Abate et al. 2000
Cabbage	*Plutella xylostella*	81–91	Ethiopia	Ayalew 2006
Cabbage	*Plutella xylostella*	38	Ghana	Asare-Bediako et al. 2010
Cucurbits	Begomoviruses	50	India	Varma and Malathi 2003
Mango	Fruit flies	30	Senegal	Ndiaye et al. 2008
Mango	Fruit flies	Up to 75	Benin	Vayssières et al. 2009a, b
Tomato	*Helicoverpa armigera*	36–38	Pakistan	Sajjad et al. 2011
Tomato	Tomato yellow leaf curl virus	Up to 95	Dominican Republic	Polston et al. 1999
Tomato	Tomato yellow leaf curl virus	1–100	Florida	Polston et al. 1999
Onion	*Thrips tabaci*	29–59	Kenya	Waiganjo et al. 2008
Tomato	*Ralstonia solanacearum*	0–100	Burkina Faso	D'Arondel de Hayes and Huyez 1973
Citrus	*Phytophthora spp.*	30–90	Florida	Cacciola and Magnano di San Lio 2008

100 % according to climatic and cultural conditions. The presence of one pest or one disease could prevent a horticultural crop from being grown or a harvest from being obtained. This is the case for *Ralstonia solanacearum* in the lowlands of Burkina Faso which prevents tomato crop without a cultivar resistant to this disease (rootstock or scion) (D'Arondel de Hayes and Huyez 1973). Tomato yellow leaf curl virus transmitted by the whitefly *Bemisia tabaci* has prevented harvests of any tomato commercial fruits in various areas (Pico et al. 1996). As a result, the high risk of significant harvest reduction or even loss has led farmers to widely use pesticide applications with the objective of security.

3 Pesticides use by small farmers

Though some data could be acquired from general statistics on pesticides use in Africa on crop production, it is difficult to get global data about their use in fruit and vegetable production. Very few global data are available on pesticide consumption. FAO (Food and Agriculture Organization) gives figures for only a very small number of African countries for all crops (Table 3). As a result, the proportion of pesticides devoted to fruits and vegetables remains impossible to estimate from official statistics, all the more so for those used by small farmers. So, the general information provided by official statistics needed to be complemented by specific studies. Hence, most of the studies mentioned below have been obtained at local and market levels.

Africa has the lowest rate of pesticide use in the world (Abate et al. 2000) but vegetable production may appear as an exception. Table 4 presents some data from local studies about the use of synthetic chemical products by small farmers in different African countries for vegetable production. The results show the high dependency of farmers on chemical control in vegetable production. Quick results obtained shortly after pesticide application probably encourage farmers to rely more on pesticides than on other pest control methods, especially in the case of short-cycle crops (Ngowi et al. 2007).

3.1 Pesticides and regulations

Despite the risks, the use of pesticides has been encouraged by most government extension programs in Africa, from the 1970s. Recommendations were similar to those in developed countries regarding the environmental and health risks. However, in the 1990s, the structural adjustment policies caused the decline of input subsidies and extension services, contributing to less monitoring from the government and more informal channels for pesticide supplies. For instance, in Cameroon, the free distribution of fungicide through official channels dropped from 30 million packets in the mid 1980s to

Table 3 Consumption of some pesticides in Burkina Faso, Cameroon, and Ghana in 2008 (*t*) (electronic consultation May 2012 http://faostat.fao.org/)

Country	Insecticides	Herbicides	Fungicides	Estimated cultivated area (ha)	Estimated fruit and vegetable area (ha)
Burkina Faso	893	54	–	3,700,000	43,855
Cameroon	2,459	2,518	1,959	3,700,000	715,261
Ghana	3,642	7,531	1,740	5,800,000	570,960

Table 4 Proportion of farmers using chemical pesticides to control pests and diseases on vegetable production

Countries	Percentage of farmers using pesticides	Number of respondents	Number of pesticides used	Source
Benin	100	108	17	Ahouangninou et al. 2011 (vegetables)
Cameroon	100	741		Mathews et al. 2003 (all crops)
Cameroon	52	45 groups of 10 farmers	7	Sonwa et al. 2008 (cocoa)
Ghana	100	137	43	Ntow et al. 2006
Nigeria	100	150		Oluwole and Cheke 2011
Tanzania	100	61	41	Ngowi et al. 2007
Togo		79	87	Kanda et al. 2009 (vegetables)
Zimbabwe	92	12	NA	Sibanda et al. 2000 (vegetables)

NA not available

less than 3 million packets in 1993 (Varlet and Berry 1997). And, in 1987, only 3 % of farmers in the South West Province have ever used pesticides, while only 14 % have ever been visited by extension services (Almy and Besong 1987). However, by the year 2000, other surveys revealed an increase of adoption rates for pesticides, of as high as 50 % among farmers (Parrot et al. 2008a, b; Sonwa et al. 2008). Despite the cancelation of subsidies in African agriculture, the use of pesticides has increased in quantity. For instance, the import value of pesticides in Central, East, and West Africa has increased by 261 % from 2000 to 2010 to reach US$901,645,000 (Table 5).

Pesticides used on fruits and vegetables in six sub-Saharan countries are listed in Table 6. Most of them are registered in the respective countries, though not always for vegetable protection (i.e., endosulfan). The use of pesticides is sometimes described for each crop, tomato for instance, or groups of crops as vegetables (Cameroon, Tanzania). In addition, the regulation of pesticides is generally going through rapid changes. Lindane is now a banned insecticide. Endosulfan has been banned since 2008 by the *Comité Sahélien des Pesticides* (CSP 2012). In fact, conformity between uses and regulations is unknown. For instance, cotton cultivation is the dominant livelihood strategy in West African savannah zones, and increasing concerns exist about pesticide use for this crop in Mali (Mamadou et al. 2001), in Burkina Faso, and in Benin (Tovignan et al. 2001; Pazou et al. 2006). Ahouangninou et al. (2012) showed that among the 15 pesticides used in Benin market gardens, only two of them were allowed on vegetable crops by the CNAC ([National Committee for Approval and Testing of Phytopharmaceutical Products], Republic of Benin) in January 2012, namely, lambda-cyhalothrin and acetaprimid; 3 of them were allowed with no crop specificity, namely, cypermethrin and deltamethrin. In Benin, fruit growers used insecticides registered for cotton growing (Vayssières 2007), such as (i) endosulfan, (ii) Calthio DS (lindane+thirame), (iii) Calthio E (endosulfan+thirame), (iv) gammalin (lindane), and (v) Apron (metalaxyl+ difenoconazole+thiamethoxam) to spray on fruit crops (mango, citrus, papaya, avocado).

Table 5 Import value of pesticides in some African regions (US$1,000) from FAOSTAT

Region	Year		
	1990	2000	2010
West Africa	106,839	163,324	500,008
Central Africa	30,102	27,625	47,270
East Africa	146,634	155,163	354,367
Total	283,575	346,112 (+122 %)	901,645 (+261 %)

3.2 Diversity of pesticides

Pesticide use varies greatly in terms of frequency, quantities of active ingredient, mixture, pesticide volume, application practice, and, hence, associated risks. Fruit and vegetable (F&V) farmers use a wide range of chemicals, such as fungicides, insecticides and/or acaricides, nematicides, and herbicides (Table 6).

Among the different categories of pesticides, insecticides and fungicides appear to be the most used in African horticulture. For instance, in the vegetable growing area of Tori Bossito, 50 km from the city of Cotonou, Benin, 100 % of growers used insecticide; 68 % used fungicide; and 3 % used nematicide (Ahouangninou et al. 2011). In Ghana, the use of herbicides (44 % of farmers) appears more prevalent than in other African countries. Moreover, though the fungicides (23 % of farmers) are used in Ghana, their application does not seem necessary, although tomatoes are frequently affected by diseases according to many farmers (Ntow et al., 2006). In northern Tanzania, the pesticides used were insecticides (59 %), fungicides (29 %), and herbicides (10 %) (Ngowi et al. 2007). Horticultural African uses seem different from

Table 6 Main active ingredients used by small farmers in vegetable and fruit production from surveys in Benin, Ghana, Madagascar, Nigeria, and Tanzania

Crops	Active ingredient			
	Insecticides	Fungicides	Nematicides	Herbicides
Vegetables: onion, tomato, cabbage (Ngowi et al. 2007) (Tanzania)	Profenofos, endosulfan, lambda-cyhalothrin, cypermethrin, chlorpyriphos	Mancozeb, metalaxyl, copper sulfate, sulfur flutriaflo PP,		2-4D amine
Tomato (Mathews et al. 2003) (Cameroon)	Cypermethrin, chlorpyrifos, endosulfan, carbaryl, deltamethrin, dimethoate, acephate, profenofos, metamidophos	Metalaxyl, mancozeb cuprous oxide, copper hydroxide, copper oxychloride, maneb	Ethoprophos,	Glyphosate, paraquat
Various species (Ntow et al. 2006) (Ghana)	Cypermetrhin, chlorpyrifos, endosulfan, lambda-cyhalothrin, deltamethrin, dimethoate	Metalaxyl, mancozeb thiophanate-methyl, carbendazim, benomyl		Pendimethalin, 2,4-D, propanil, MCPA-thioethyl, oxadiazon, oxyfluorfen, bensulfuron-methyl, glyphosate, paraquat-dichloride, acifluorfen, metolachlor, phenmediphan
Various species (Ahouangninou et al. 2011) (Benin)	Profenofos, endosulfan, lambda-cyhalothrin, cypermethrin, cyfluthrin, chlorpyriphos, deltamethrin, acetamiprid	Metalaxyl, mancozeb thiophanate-methyl, carbendazim, benomyl, maneb, copper oxide	Carbofuran	
Cocoa, rice, fruit, vegetables, cowpea (Oluwole and Cheke 2011) (Nigeria)	Monocrotophos, lindane, thiamethoxam	Metalaxyl, difeconazole, copper sulfate, mancozeb		Atrazin, paraquat, metolachlor, glyphosate
Watercress (Dabat et al. 2008) (Madagascar)	Malathion, endosulfan, lambda-cyhalothrin			

worldwide consumption, where herbicides represent 50 % of all plant-protection products use (Cooper and Dobson 2007).

Fruit and vegetable production used greater variety of compounds (over 20 in Benin and Senegal) than other crops (Williamson et al. 2008). The current insecticides used by farmers belong to the main families of synthetic pesticides: organophosphates, carbamates, pyrethroids, and organochlorines. In the case of vegetable production in Niayes (Senegal), organophosphates are commonly used (36–48 % of active ingredients), followed by organochlorines (12–16 %), pyrethroids (4–18 %), and carbamates (6–10 %) (Cissé et al. 2008). In Ghana, Ntow et al. (2006) reported that cypermethrin, lambda-cyhalothrin, and endosulfan were the most effective against insects, according to farmers' perceptions. But, pesticide mixtures that contain up to five different pesticides in a single tank are commonly observed (Ngowi et al. 2007; Sibanda et al. 2000).

Pesticides used in horticulture often take advantage of regulations and practices set up for other crops, resulting in dangerous synergies. In Benin, vegetable farmers mainly used insecticides registered for cotton protection (Ahouangninou et al. 2011). Six liters of insecticide per hectare are distributed on credit each year to cotton farmers by ginning companies. Because cotton farmers in Benin used only 4 L/ha on average for cotton protection (Toukon et al. 2005), a high quantity of insecticides initially dedicated to cotton is sold on the black market and used on other crops such as vegetables.

3.3 Frequency of application

There are few global data available on that subject; as a result, we have summarized the following published case studies. In Tanzania, Ngowi et al. (2007) observed from 5 to 16 pesticide applications per crop, with onion growing the most processed, followed by tomatoes and cabbages. The base frequency was a weekly application in many situations (Ngowi et al. 2007; Ntow et al. 2006). In Senegal, weekly frequencies of pesticide applications on vegetable crops depended on the areas of cultivation: 23 % of farmers in Dakar, but 50 and 53 % of farmers in Mboro and in Gandiolais, respectively (Cissé et al. 2008). This was mainly due to the duration of the crop cycles (lettuce vs. tomatoes and onion). In Malawi, farmers spray on average tomatoes 19 times and cabbage 14 times (Orr and Ritchie 2004). In the production of watercress in Antananarivo, insecticide applications were once to three times for a 6–8-week cycle (Dabat et al. 2008). As a result, and despite the fact that this was not studied in most case studies, we believe that the frequency of the routine certainly revealed preventive properties against pest attacks. As an example, in Senegal, only 2–31 % of producers, respectively, in Gandiolais and Dakar, reported applying pesticides based on symptoms of attacks (Cissé et al. 2008). In Benin, a socio-economic analysis of the use of pesticides demonstrated that three factors influenced the use of pesticides by the farmers: the gender, the irrigation method, and the crop, but not recognition of the pests (Singbo et al. 2008).

3.4 The application equipment

In most studies, the most common material used is the knapsack sprayer not only by small vegetable famers (Ngowi et al. 2007; Sibanda et al. 2000) but also for food crops, coffee, and cocoa (Matthews et al. 2003). Risks associated with the use of these devices carried on the back were numerous sharp edges of equipment, narrow belts, tank weight, size of the filling opening, leakage (Sibanda et al. 2000), and the shape of the hoses. Matthews et al. (2003) mentioned 45 % of defects (faults) from the nozzles (nozzles) and 29 % from the valves (valves trigger) in the whole study in Cameroon. Sibanda et al. (2000) also emphasized the misuse of nozzles. The duration of use was 10 years, with up to 35 years of use for at least some devices (Matthews et al. 2003). A large proportion of small producers did not wear protective clothing: 85 % in Cameroon (Matthews et al. 2003), 92 % in Zimbabwe (Sibanda et al. 2000), 85 % in Senegal (Cissé et al. 2008), and 100 % in Lome (Tallaki 2005). As with the packaging, the rinsing water and storage of products and devices were only applied correctly in a small proportion of cases (about 20 %) (Matthews et al. 2003). They were often left in the fields undergoing applications of pesticides on plants and spontaneous flora, which led to the absolutely uncontrolled environmental contamination. The number and type of chemical applications varied according to the season and the crop. Product concentration in the water tank appeared to be rather lower than the recommended concentration: between 20 and 60 % of the recommended dose for Sibanda et al. (2000). The volume of active ingredient applied was highly variable compared with the technical recommendations, from 13 to 270 %. New materials had been tested by modifying the orientation of the nozzle to direct the spray from low to high (Sibanda et al. 2000).

3.5 Causes of poor pesticide practices

Stakeholders in the pesticide industry are calling for improved monitoring for agro-chemical inputs and training among farmers (Parrot et al. 2008b). Ajayi and Akinnifesi (2007) cited the following direct causes for bad practices in pesticide use on farm fields: the absence of instructions, illiteracy among farmers, lack of awareness about the danger of misuse, the difficulty of extrapolating the dosage from a hectare basis to very small areas, unsuitability of the products in respect of the problem source, lack of knowledge of pests and diseases, etc. Lack of knowledge alone is not sufficient to explain poor pesticide practices among sub-Saharan African small-scale farmers.

Wilson and Tisdell (2001) mentioned that competitive market systems encourage the adoption of biophysically unsustainable techniques which lower current costs and increase yields in the short run and that short-term health effects arising from pesticide use are underestimated by farmers as diagnoses are hindered by poor medical facilities.

Sustainable practices require a relatively long-term perspective, whereas pesticide practices are still perceived to provide higher returns in the short run. The urban transition and the rapid pace of change of human settlements and livelihoods probably hinder sustainable pesticide practices. The lack of long-term incentives may prevent investments in sustainable agricultural practices (lack of property rights, lower returns in farming than in non-farm activities). This is particularly true for migrants, as they are not necessarily familiar with farming at all.

The urbanization process increases the intensification of agriculture and the emergence of fruit and vegetable farming, which need high levels of pesticides. Fruits and more particularly vegetable farming are suited for urban and peri-urban agriculture, as they provide a higher return per hectare than other crops in a context of high land pressure (De Bon et al. 2010). Higher population densities contribute to improved market access for farmers as well as improved technologies including agrochemical inputs (Keys and McConnell 2005).

4 Risk assessment of pesticides uses

4.1 Resistance of bio-aggressors to pesticides

Pesticide use in combination may delay the onset of insecticide resistance (Martin et al. 2003). But, it covers a wider range of enemies and thus leads to a more systematic destruction of natural enemies. A survey of mites on *Solanum spp.* and *Amaranthus spp.* in all growing areas of southern Benin did not show any predatory mites except in the untreated plots of the IITA (International Institute of Tropical Agriculture) research station (Adango et al. 2006). Moreover, the more often the same insecticide is used, the more rapidly a resistant population is selected. In that case, farmers will increase the dosage and the frequency of spraying. In West Africa, four of the major vegetable pests are already resistant to the insecticides used for their control: the tomato bollworm *Helicoverpa armigera* is resistant to pyrethroids (Martin et al. 2000); the whitefly *B. tabaci* is resistant to pyrethroids, organophosphates, and neonicotinoids (Houndete et al. 2010); the aphid *Aphis gossypii* is resistant to pyrethroids and organophosphates (Carletto et al. 2010); and the diamond back moth *Plutella xylostella* is resistant to pyrethroids. As a result, the choice of chemical insecticides is more and more difficult, and the choice of crop will be influenced by the low efficiency of the chemicals.

4.2 Human health

Only recently, the risks associated with pesticide uses in Africa have begun to be documented in scientific papers for human health of both consumers and workers (Amoah et al. 2006; Ntow et al. 2006; Ngowi et al. 2007; Williamson et al. 2008; Saethre et al. 2011; Ahouangninou et al. 2012). Depending on the studies, human health risks were evaluated by interviews with farmers (diseases symptoms), blood and urine analysis, or pesticide residues in/on vegetables in the markets. In South Africa, 73 % of children with atopic dermatitis had been exposed to household pesticides; most childhood exposure (89 %) occurred in the informal settlements, followed by 78 % in urban areas and 63 % in the rural areas (Tolosana et al. 2009). Ngowi et al. (2007) mentioned the high variation in health expenditure among farmers in Tanzania, from no cost for 61 % of the farmers to a value between US$0.018–116 in a year for the other 39 %. In Ghana, an estimate of the health costs in terms of average number of days off sick after treatment has been calculated: 21.7 days after cotton spraying and 15.1 days after cowpea spraying. The medical treatment costs have been estimated at US$53.12 (Williamson et al. 2008).

Most workers are not protected from exposure to pesticides, leading to high-potential risks. Even water and food may be contaminated through the use of empty pesticide containers (Ondieki 1996).

4.3 Environment

Few papers have been published on the environmental impacts of pesticide use in tropical areas and particularly in Africa. For the environment, measurements are taken in water, soil, or air. Evaluation of the pesticide eco-toxicology could be carried out by various indexes, such as the Environmental Impact Quotient (EIQ), the Environment Risk Index (ERI) from the Quebec-NIPH (National Institute of Public Health), or the Pesticide Environmental Impact (IPEST). EIQ has been used in tropical developing countries, on the potato (Kromann et al. 2011), and cruciferous vegetables (Badenes-Perez 2006). Bues et al. (2004) have shown an increase in the EIQ and IPEST on tomato in tropical areas (Reunion Island) compared to Mediterranean areas. Ahouangninou et al. (2012) in Benin market gardens showed that the highest ERIs were obtained for carbofuran, chlorpyriphos ethyl, and endosulfan. Regarding the different climate conditions in Africa, compared to Europe, there is a need to quantify ambient pesticides concentrations and judge related risks for local consumers and the environment. Indeed, the risk may develop from accumulation of pesticide residues in soil and on plant surfaces (Rosendahl et al. 2009).

Misuses of pesticide increase environmental risks in high-population-density areas. The use of chemical insecticides among the peri-urban vegetable and fruit producers in the suburbs of Cotonou (and other West African capitals) has been increasing to such a level that major insect pests have developed resistance to pesticides (see above; Atcha-Ahowé et al. 2009). Other negative effects are actually increasing insecticide resistance in insect vectors due to the dispersion of insecticides from peri-urban vegetable and fruit areas to mosquito breeding sites (Corbel et al. 2007).

5 Reducing pesticides overuse and misuse

Faced with this situation, it is urgent to develop new methods such as integrated pest management (IPM). IPM has been successfully implemented in a wide range of crops and agro-climatic zones (Matteson 2000; Bajwa and Kogan 2003). It is a holistic approach that views the agro-ecosystem as an inter-related whole and uses a variety of biological, cropping, genetic, physical, and agro-ecological techniques that maintain pests below economic injury levels (Fig. 2). Agro-ecological techniques are based on the agro-ecology approach, which is a broad concept combining different sources of knowledge: local knowledge based on empirical specific transmission and acquisition methods and experimental and analytical knowledge. The underlying hypothesis is that increasing biodiversity in the agro-horticultural system will allow reduction of pesticide use by favoring ecological regulation mechanisms. Their rules of application in the field are well defined, and the use of chemical pesticides is not entirely banned (Malézieux 2012; Ratnadass et al. 2012). The assumption is that IPM guarantees yield, reduces costs, is environmentally friendly, and contributes to sustainable agriculture.

5.1 The case of fruit crops

Fruit crops are perennial crops and are cultivated on a long-term basis, unlike vegetables which are short-cycle, of between 2 and 8 months, as well as cash crops. Is there a different approach for pest control between the perennial and the annual horticultural crops? While the pests and diseases of fruit-tree crops are described in various papers, there are very few references on the fruit-tree grower practices for plant protection and pesticide use. A short synthesis of three fruit crop case samples in West Africa will try to provide some trends on some past and present practices and the IPM strategies including biological control options (Fig. 3).

As past practices, the sanitary practices were a combination of some prophylactic measures and chemical pesticide applications against some of the fruit-tree crop pests. The choice of chemical control was linked to the existing chemicals that could have an effect on bio-aggressors and the need to maintain the tree crops for several years. On the date palm tree (*Phoenix dactilifera* L.) scale, insects, especially *Parlatoria blanchardi* Targ, are key pests in many West African countries, attaining population levels of up to 60 scales/cm^2 and causing yield losses of up to 60 %. Local pest management practices in the Islamic Republic of Mauritania (Adrar, Tagant, etc.) included the following: (i) cutting and burning scale-infested palms and (ii) sprays of DDT or lindane against the date palm scale, *P. blanchardi* (Hemiptera Diaspididae) on the date palm (De Montaigne and Fall 1986). In the highlands of Guinea, more than 30 % of citrus production was damaged by the false codling moth *Thaumatotibia leucotreta* Meyrick (Lepidoptera Tortricidae) (Vayssières 1986). The local pest management practices were based partly on (i) some sanitary practices, such as the destruction of infested citrus, and (ii) the use of chemical pesticides such as cyfluthrine or diazinon. In Benin, more than 50 % of the mango production is damaged by a complex of fruit fly species (Vayssières et al. 2009a). In mango and citrus crops, farmers mainly relied upon the use of chemical pesticides such as endosulfan, lindane, and thiram in some large plantations (Benin, Mali, Côte d'Ivoire, and Senegal).

Fig. 2 Intercropping in a lowland field in South of Benin: maize, West African sorrel (*Corchorus olitorius*), and African eggplant (*Solanum macrocarpon*) (J. Huat)

Fig. 3 Traditional intercropping cowpea in mango orchards in the Niaye area (Senegal) during rainy season (H. de Bon)

The alternative management strategies proposed by scientists and fruit-tree research and development projects to improve control of the bioagressors were diverse and based on environmental friendly methods: biological control and IPM sensu lato. The control of *P. blanchardi* on the date palm tree was based on the augmentation of biological control by large-scale releases of ladybeetles. In the mid 1970s, the ladybeetle, *Chilocorus bipustulatus* var. *iranensis* (Coleoptera Coccinellidae), was released by the French research institutions as Institut National de la Recherche Agronomique (INRA) and Groupe d'Etudes et de Recherches pour le Développement de l'Agronomie Tropicale (GERDAT) for biological control of this scale insect (Iperti et al. 1970). Given the high level of predation by *C. bipustulatus*, date palm scale populations were currently kept under control. At the end of the 1980s and early 90s, the presence of the lady beetle was still confirmed in palm groves in humid areas (e.g., Terjit) (Vayssières et al. 1991). However, in drier palm groves, the beetle could not overcome the cold and dry season with the strong Harmattan wind from the desert. The false codling moth on citruses was controlled by the use of delta traps in Guinea with sexual pheromones (Vayssières 1995). They were used to monitor the presence of pests, as control tools to capture insects, and also lures to attract insects to insecticidal baits. In this case, pest monitoring and control were biologically achieved. But the cost of the material and the pheromones was a limiting factor for the dissemination of this IPM technique in Guinea and other West-African countries. For mango fruit flies, the solution is based on biological control by weaver ants (*Oecophylla longinoda*) (Fig. 4) without any pesticide. If there were applications of chemical pesticides in orchards, then coccids can reach outbreak levels (Kenne et al. 2003). So, the insect damage was often worst on fruit crops after chemical insecticide sprays.

Fig. 4 Ants (*Oecophylla longinoda*) capturing fruit flies larvae in a mango, picture taken in a mango orchard in Central Benin (JF. Vayssières)

To control fruit flies, the solution proposed by scientists is an IPM package based on orchard sanitation, GF-120 bait sprays (Vayssières et al. 2009b) and biological control with weaver ants (Van Mele et al. 2007; Adandonon et al. 2009) and parasitoids. In these examples, the solutions proposed by scientists were based on biological control and monitoring. This IPM package is used by farmers in Benin, and the innovation adoption of weaver ants as biological control agents used in mango pilot orchards in the framework of West African fruit fly initiative (WAFFI) is especially successful.

5.2 The case of vegetable crops

The use of physical barriers such as greenhouses or plastic tunnels to protect vegetable crops has developed significantly worldwide over the past 20 years, mainly against invasive pest species transmitting infectious diseases, such as tomato yellow leaf curl virus (TYLCV) transmitted by the whitefly *B. tabaci* (Berlinger et al. 1996). The development of insect-proof nets permitted the cost-effective production of tomato and other vegetables, particularly in the Mediterranean region. The various forms of insect-proof nets and their efficacy and the importance of physical control methods for agriculture have been reviewed extensively (Weintraub 2009). In tropical regions with high level of temperature and humidity, the use of net with fine mesh, i.e., lower than 50-mesh against whiteflies, reduces ventilation, increasing the risk of plant pathogen development. However a new technique using nets to protect cabbages was successfully evaluated on a research station and in farmers' fields in Southern Benin. These nets covering cabbages on 50-cm wood sticks were effective against the major pests, such as the Lepidoptera *P. xylostella* and *Hellula undalis*. The use of nets on cabbages permitted a significantly higher yield than with chemical spraying (Martin et al. 2006). But, nets did not protect cabbages against the Lepidoptera *Spodoptera littoralis*, which lays its eggs on the net, and the aphid *Lipaphis erysimi* which can cross through the net (Talekar et al. 2003). However promising results have been shown in Benin and France with a pyrethroid-treated net to protect cabbages against the aphid *L. erysimi* and *Myzus persicae*, compared with an untreated net (Martin et al. 2006). The efficacy of untreated and treated nets in protecting cabbage and tomato nurseries were confirmed on a station in Kenya (Gogo et al. 2012). Bleeker et al. (1966) showed that whiteflies choose their host plant by the odor and the color of the plant, and they noticed that a net concealed the shape and the color of the plant. Thus a combination of a visual barrier reducing the orientation and attraction to whiteflies with a repellent product would reduce the rate of *B. tabaci* crossing through the net, thereby reducing the risk of virus transmission such as the TYLCV (Polston and Lapidot 2007). Thus, the protection of vegetables with nets seems to be an economically viable method because it can be reused several times, in addition to its environmental benefits. The only difficulty with this resource poor farmers in Benin (and possibly elsewhere) will face is the initial investment in material. Using nets to protect vegetables has the additional advantage that it can be easily combined with other IPM techniques facilitating a global push-pull strategy. So, IPM is working for both fruit crops and vegetable crops.

6 Conclusion

For more than 40 years, the use of chemical pesticides in fruit and vegetable production has been developing in plenty countries through sub-Saharan Africa. The range of pesticides is very large; most of them are chemicals used since the 50s, and some of them are no longer used in Europe. Furthermore, their frequency of application is quite high, especially on vegetable crops. In sub-Saharan Africa, more generally, pesticide choice, quality, and frequency of application and use are not hardly controlled. Quite often, pesticides not licensed for use on food crops (typically cotton pesticides) end up in the food chain. This endangers both the workers applying pesticides and consumers' health. We also encounter phenomenon of resistance of pests to pesticide more and more frequently. Globally, there appears to be both a misuse as overuse of pesticides, and so, there is a strong necessity for implementing new efficient IPM approaches.

The increasing of the urbanization process, the prevalence of the informal sector, and the diverse frauds about local production of pesticides will increase the risk inherent of pesticide misuse and overuse. But some positive alternative methods have been already developed such as physical barriers, cropping practices, genetic improvements, semiochemicals use, biological control options with beneficial insects and mycopesticides. This large IPM issue should be enhanced in relation to training especially in horticultural value chains through farm field schools (FFS). The training of all the stakeholders, from the wholesaler to the retailers and farmers, appears to be one of the most effective methods to promote IPM. In terms of the farmers, IPM tries to integrate all the components of production and all eco-environmentally friendly components of crop protection.

Emerging markets for organic and sustainably managed horticultural products should help to boost investment in IPM options and especially biological control (Fig. 2). For instance, the use of entomopathogenic fungi and bio-control insects is largely promoted in West Africa through the IITA station of Cotonou on horticultural productions with *Beauveria bassiana* (n strains), *Metarhizium anisopliae* (n strains) against several vegetable pests, and natural enemies as *O. longinoda* (weaver ants) against several mango and also cashew pests. Still, continuous efforts are needed to develop and fully establish IPM best bets in the curriculum of the national extension system and to counterbalance the pesticide misuse and overuse. Adherence to strict regulations on crop pesticides residues, in order to comply with the Global Partnership for Safe and Sustainable Agriculture, is giving farmer organizations incentives to highly reduce pesticide misuse and overuse and promote IPM best bets. Implementing agro-ecological approach through IPM should reduce poverty, create jobs, and increase African earnings and food security by developing efficient and sustainable crop protection.

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