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Evaluation of Pesticide Application Equipment Efficiency for Pests Control and Safety of the users, a Review

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Authors' contributions

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

The technical state of the equipment used for pesticide application could guarantee effectiveness of pesticide and the safety of the users. Different types of nozzles and the portable, tractor-drawn and aerial equipment are deployed through alternative methods of application. In particular, more vital information is needed to ensure better choice of equipment, especially the nozzles, and calibration to ensure the correct dosage is applied. More concern for inherent danger has engendered health and safety legislation leading towards linking packaging of pesticides with the application equipment to provide a closed transfer system minimizing operator exposure. Synthetic pesticides are extensively deployed in the control of harmful pests and thus prevent crop yield losses or product damage in modern agriculture. Therefore pesticide of high biological activity usually exhibited long persistence in the environment and caused undesirable effects to human health. However, farmers may be exposed to the effect of pesticides even when performing activities not directly related to pesticide use. Hence, farmers can face major exposure from manual direct spray, drift from neighboring fields, or by contact with pesticide residues on the treated crop or soil. Production of cash crop is still dependent on pesticides to attain acceptable levels of high crop yield. However, poor insecticide coverage resulting from the use of inefficient application equipment, wrong timing, irregularity and wrong technique of spraying are capable of accelerating the rate at which insects

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develop resistance to insecticides. Hence, along with the screening of new insecticides, fungicides and herbicides, new spraying pumps are usually evaluated by the Cocoa Research Institute of Nigeria (CRIN), for their efficiency before they are recommended for use in the application of cocoa pesticides and spraying equipment in Nigeria.

Keywords: Pesticide; spraying equipment; operator; user; protective equipment.

1. INTRODUCTION

Pesticides are chemical substances used to reduce or eradicate completely a great variety of harmful pests and vermin, particularly in agriculture. Its use is a seasonal, but intermittent task, spanning only a wide range of tasks undertaken by farmers. They are used in crop protection and public health to control vector-borne infectious diseases. Although, high biological activity of pesticides coupled with long persistence in the environment may cause undesirable effects to human health. Improper handling of pesticides may result in severe acute poisonings and adverse health effects from varied degree of exposures [1]. Majority of users may be exposed to widespread diffusion of pesticides due to the nature of occupation. However occupational exposure usually occurs among workers engaged in the manufacture of pesticides and specific users in public health. Likewise among farmers and professional applicators of pesticides in the agricultural sector [1-4]. Several scientists reported that non-availability of suitable application equipment, besides the use of adulterated and banned insecticides, supply uncertainties, high costs and inadequate knowledge by farmers about proper use of pesticide products are major problems of agricultural production in Nigeria and other developing countries [5,6].

In developing nations, many unapproved cheap chemicals are used extensively for insect pest control, which is responsible for serious acute health problems and environmental pollution [7-9]. Consequently, farmers and farm workers form a major group of workers that are consistently exposed to pesticides, thus face greater risk than typical non-agricultural workers. The type of pesticides, the frequency of use and the application method are usually different based on the cropping system and the specific crops grown. In Europe, in spite of international efforts to promote the sustainable use of pesticides in agriculture and drastic reduction in use in some other countries, though overall pesticide use did not decline substantially in the WHO European Region during the period of 1990s [10]. However, USA is implicated of using the greatest amount of pesticide in agriculture [11].

2. SPRAYING EQUIPMENT

Sprayer is a device deploys to spray liquids like water, insecticides, and pesticides as well as herbicides and fertilizers to crops in agriculture. Pesticide application equipment has been introduced into the African farming systems, including the pesticides to be applied, ever since they were used in the industrialized developed countries. Different techniques available have been practically introduced more or less successfully. Among the three major groups of application equipment, e.g. portable, tractor mounted and aeroplane mounted, only the portable equipment is used on a large scale in West Africa. In Nigeria certified agency e.g. Cocoa Research Institute, Ibadan (CRIN) is saddled with the responsibility to evaluate regularly new spraying pumps for their efficiency before they are recommended or disapproved for use by cocoa farmers (Table 1). Matthews et al., [12] however described explicitly the different types of nozzles and the portable, tractor-drawn and aerial equipment complemented by alternative methods of pesticide application. In the developed countries more concerns has been the health and safety legislation leading towards linking packaging of pesticides, with the application equipment to provide a closed transfer system minimizing operator exposure. Therefore, adoption of integrated pest management (IPM) to reduce the use of pesticides, more accurate and timely application is of increasing importance [13]. However, more information is needed to ensure better choice of equipment, especially the nozzles, and calibration to ensure the correct dosage is applied through the hydraulic nozzles. This is the key part of the atomization of liquid sprays into droplets. Liquid passing through a small orifice in the nozzle tip forms a sheet, which subsequently breaks into droplets. The process of break-up includes rim disintegration where droplets are thrown from the edge of the sheet, but most droplets are formed by perforated sheet

disintegration. An increasing number of holes develop in the sheet, separated by thin ligaments of liquid that are unstable. These ligaments break up into droplets and smaller ligaments, which ultimately produce smaller satellite droplets. Sometimes under turbulent conditions, wavy sheet disintegration occurs where sections of the sheet may break away. The break-up of the sheet is also affected by the physical property of the formulation, including dynamic surface tension and viscosity of the liquid. If the sheet disintegrates closer to the nozzle, larger droplets are formed, whereas if the sheet remains coherent and stretches to form a very thin film before break-up, smaller droplets are produced [14]. Irrespective of the mode of break-up, hydraulic nozzles produce droplets of a wide range of sizes [15]. In most cases pesticides are applied using either a nozzle or a spinning disc to disperse the spraying liquid into a spraying cloud of small droplets.

Nonetheless, agricultural sprayers have components like spray nozzle, liquid tank, sprayer pump, pressure regulator, valves and fluid plumbing and some have spray gun. This agriculture sprayer comes in various size, design and performance specifications. They are range from small sprayers to very large sprayers in size that helps to cover small area of land to extensive land. The technical state of the equipment to a large extent determined t he safety and effectiveness of pesticide use.

There are number of sprayers which are designed for different spraying applications like gardening, crops, trees, fruit, livestock needs, and weed control. The sprayers included Hand-operated hydraulic sprayer, Knapsack Sprayer, Portable Power Sprayer, Knapsack Power Sprayer, Mist Dust Sprayer, HTP Sprayers and Orchard Sprayers.

Table 1. List of sprayers tested and recommended for use in Nigeria

Spraying equipment trade name		Manufacturer/Local company representative
S/N	**Pneumatic knapsack sprayers**	
1	Maruyama MHCB	Marolex SP Zo. O Poland/Bolu investment Nigeria Ltd
2	CP 100 falcon	Hardi International A/S of Denmark/Dizengoff Coy. Ltd Nig
3	CP 148	Indo German Agril Sprayer/Harvest Field ind. Ltd. Nigeria
4	Flora Birchmeier	Goizper S. Coop, Spain/The Candel Company, Nigeria
5	Gloria 172 RT	Indo German Agril Sprayer/Kasco House Maiduguri Rd Kano
6	Four Oaks	Hardi International A/S of Denmark/Dizengoff Coy. Ltd Nig
7	Solo Jet Pak – 425	Solo sprayers limited, England/Harvest Field ind. Ltd. Nig
8	AS- Motor	Kwazar Corp. S.C., Poland/Kasco House Maiduguri Rd Kano
9	Maruyama DMD 140	Marolex SP Zo. O Poland/Bolu investment Nigeria Ltd
10	Ms – Iyanmer	Goizper S. Coop, Spain The Candel Company, Nigeria
11	Solo 423	Solo sprayers limited, England/Harvest Field ind. Ltd. Nig
S/N	**Hydraulic knapsack sprayers**	
1	Pulmic PM 120	Sanz hnos of Spain/The Candel Company, Nigeria
2	Jacto PJ - 16	Maquinas Agricolas Jacto S.A./Dizengoff Coy. Ltd Nigeria
3	Rosy 16	Di Martino, Italy/Saro Agro Science, Nigeria
4	Solo	Solo sprayers Ltd., England/Harvest Field ind. Ltd. Nigeria
5	Neptune 15	Kwazar Corp. S.C., Poland/Lajibam Auto&Agric concerns Ltd Nig.
6	Osatu	Goizper S. Coop, Spain/Adewale O. Trading stores Ltd. Nig.
7	CP 15	Hardi International A/S of Denmark/Nunees Nig. Ltd.
8	Kizan KJ - 16	Indo German Agril Sprayer/African Agro Co Ltd.,

Spraying equipment trade name		Manufacturer/Local company representative
		Nigeria
9	Volpi 78	Davide Luigi Volpi S.P.A. Italy/Jubaili Agrotec Ltd., Nigeria
10	Titan heavy duty	Marolex SP Zo. O Poland/Komes Ventures Ltd., Nigeria
11	Mob	MOB Company UK/Harvest Field ind. Ltd. Nig
12	Garden 15	Di Martino, S.P.A. Italy&Fem-Fun Nig. Ltd/Timmy Fak Gen Works Ltd
S/N	**Trombone sprayers**	
1	Solo 28 MKI	Solo sprayers limited/Adewale Oladayo Trad. Store Ltd Nig
2	Matabi Trombone	Matabi Spain/Insis Crop Care Nigeria
3	Hudson Trombone 61224	HD Hudson Asia Ltd/Harvest Field industries Ltd. Nigeria
4	Hudson Trombone 612219	HD Hudson Asia Ltd/Harvest Field industries Ltd. Nigeria
S/N	**Motorized knapsack sprayer**	
1	ANVL/Tornado WFB 18	Agro Nigerian ventures Ltd/ Lajibam Auto&Agric concerns
S/N	**Swing fog machines**	
1	SN 11	Maquinas Agricolas Jacto S.A/Kasco House Maiduguri Rd Kano
S/N	**Hand pumps**	
1	Lancet	Indo German Agril Sprayer/Bolu investment Nigeria Ltd

Source – Asogwa and Dongo, [16]

Hand-operated hydraulic sprayer: Hydraulic energy nozzle has been mostly used because considerable flexibility can be achieved by interchanging the teats in standard nozzle body to provide a wide range of output and spray pattern at low cost. Some simple hand operated hydraulic sprayer included syringes.

Mechanism – It is a sprayer in which liquid is withdrawn from a reservoir into a pump cylinder by pulling out the plunger. The liquid is then force out through a nozzle on the compression stroke. However, this sprayer has been mostly replaced by double acting slide pump or hand compression sprayer. A small syringe type spray is useful for spot treatment e.g. Pest control in pot experiment and or Striga can be killed in a maize plot.

Knapsack Sprayer: Knapsack sprayer is convenient for spraying through hand-held nozzles that is connected to tank carried on operators back. There are three types of Knapsack controlled sprayers i.e battery, manual and battery cum manual sprayer. However, knapsack power sprayer has motor engine operated by using petrol engine i.e., 2 stroke and 4stroke engine type. It has the separate chemical tank and also has hand held nozzles.

There are two major types of knapsack sprayers:

Lever-operated knapsack sprayers - These are small-scale sprayers which are mostly used in developing countries. The design of which has changed very little since they were first manufactured. The lever operated sprayer consist of tank usually stand erect on the ground and when in use fix comfortably on the operator back like knapsack. The sprayer comprises a hand operated pump, a pressure chamber and a lance with an on and off type trigger valve with one or more nozzles. Through a hand-operated pump and a nozzle/nozzles, they produce a wide range droplet size spectrum and coverage of about 200 l/ha.

The tank was initially made from brass and mild steel but metal tanks are now very expensive. Hence, the modern trend is to use the plastic tank usually moulded from high density polythene or polypropylene incorporating an ultra violet (UV) light inhibitor. The usual capacity of the tank is about 15 litres, so that the total weight is not too excessive to be carried by the operator. The volume of spray in the tank is indicated by graduated marks moulded in plastic tanks. The tank has a large opening {of not less than 95 mm in diameter at the top to facilitate cleaning and filling} which has a tight fitting lid to prevent spray

liquid from splashing out and down the operator back. A 50 mesh filter or coarse filter is firmly positioned in the filler hole and set 50 mm into the tank.

Lever operated knapsack sprayer can be divided into those with an over arm or under arm lever and those with a piston or diaphragm pump. The piston pump is normally use where higher pressure at the nozzle are required. Secondly, the diaphragm pump is preferred when suspension are being applied which are liable to cause erosion of the piston chamber. The pump is connected to a lever, the over arm lever is easier to operate when working between plants that mix across the rows (dense canopy) as the lever is then well clear of the branches of the plant but fatigue occur very easily therefore sprayer with under arm lever are more frequently use. However, many sprayer has the facility to change the lever from left to right arm operation.

Mechanism – When using the sprayer, liquid is drawn through a valve into a pump chamber with the first stroke with the return of the lever to the original position. The liquid in the pump chamber is forced pass another valve into a pressure chamber. The first valve between the pump and tank is closed during this operation to prevent the returns of the liquid to the tank. Air is trapped in part of the pressure chamber and compressed as the liquid is forced into the chamber. Then, the compressed air forced liquid from the pressure chamber through hose to the nozzle.

Compression sprayers: The sprayers have an air pump to pressurize the spray tank and are also refer to as pneumatic sprayer. The tank is never completely filled with liquid, it is always filled to about two third (2/3) of total capacity. A space is needed above the liquid so that air can be pumped in to create pressure to maintain the flow of liquid to the nozzle. This sprayer varies in size from the small hand sprayer suitable for limited use by gardener to large knapsack sprayer. And they are use for spraying a wide range of pesticide as no agitation is provided. However, this sprayer needs to be shaken occasionally if using wettable powder formulation to prevent the suspension settling out. With these sprayers the whole of the container that contains the spraying liquid is pressurized. Sizes range from less than 5 litres to over 10 litres. The underarm lever operated type is most popular but shoulder pump sprayers and compression or pneumatic sprayers are equally widely accepted. Knapsack sprayers are used to apply any kind of pesticide (e.g. mostly insecticides, followed by fungicides and herbicides) including water, volumes range from 100 to 400 l/ha. A sprayer is more often used on cash crops such as cocoa, maize and cotton, and also on garden crops and to a lesser extent on the staple food crops probably huge cost involved.

Mist blowers belong to the group of air-carrier sprayers which provides an air stream in which droplets are projected towards the target. They produce large spray clouds and are therefore often used in tree crops though spraying volume is relatively low; 20l/ha. Mist blowers are generally used for insecticides to protect Cocoa and citrus and food crops against pest and diseases. In the same vein, Mist dust sprayer is a kind of knapsack power sprayer that spray liquid chemical in mist form while urea in granule form. Thus, ideal for quick spraying operations in orchards, tea, coffee estates & other crop plantations. It can also spray dust powder form of pesticides.

HTP sprayer is a horizontal triple piston pump with brass head, mainly used for uniform spraying with high pressure all over the operation land; it is used for multipurpose like commercial usage and agricultural usage. Portable power sprayers are operated by electric and petrol engine with the help of hose pipe. This type of sprayer doesn't have chemical tank, which is used for applying pesticides, insecticides or liquid type chemicals at extensive land coverage. Its main benefit is having long operation life and power efficiency. In this type of sprayer also we can find battery, manual and battery cum manual operated sprayers.

Spinning disc sprayer: Spinning disc sprayers comprise a plastic rotating disc, powered by batteries, to disperse the spraying liquid into very small droplets. The spraying volumes is as low as 3 litres per ha which makes the comparative advantage during time of water scarcity. Also their relative simple technique and ease of application have contributed to the widespread use of the sprayers. Cauguil (1985) reported that over 80 per cent of farmers' cotton crops in francophone Africa are sprayed with hand-held, battery-driven spinning disc sprayers. The concentration of pesticide in the spraying liquid can be very high (up to 100%) which increases the risks of phytotoxicity and intoxication of the operator. Therefore, drift of the spray cloud and total dependence on air movement for distribution of the spray cloud could be a

disadvantage. Notwithstanding the spinning disc sprayers are indeed second in use after the knapsack sprayers in most developing countries. Though, the spinning disc sprayer was reported to be even more commonly used than the knapsack sprayer in some countries. Insecticides are the most common pesticides for a spinning disc sprayer, followed by herbicides for pest control in cotton, garden crops, and other food crops.

Electrodyne sprayer: In 1979, an acid type of sprayer was developed that resembles a hand held spinning disc sprayer e.g. Micro ULVA but has no moving parts. The electrodyne sprayer is based on the system which atomizes and propels charged droplets of chemical spray by electrical forces set up between a nozzle with a positive high voltage charge, the spray droplets themselves and the earthed target crop.

Mechanisms – The liquid pesticide is confined in a bottle and it is fed by gravity into nozzle where it picks up the high voltage charge generated by four (4) batteries. The liquid leaves the bottle in a number of uniform ligaments, which breaks up into electrically charged and this mutually repellant droplets. This positively charged spray droplets move along curved electrical field lines towards around the plants covering all visible and hidden surfaces of the foliage. Due to the electrical charge some two and half (2 1/2) times more droplets impact on the target plants then if other spray systems are used. The system produces droplets of a controlled size within a spectrum range of 40-200u. The size can change by altering the voltage.

Formulations – The electrodyne is used to spray specially formulated oil base formulation of very low volatility at a rate of about 0.5 l/ha. The first special electrodyne formulation in the market was the pyrethroid insecticide “Cymbush” for use on cotton crops. A special feature of this type of sprayer is that formulation comes in a special bottle fitted with the particular nozzle and holding 750 ml of the pesticide. Thus, this combination of bottle and nozzle is called “Bozzle” and is a closed system that suffices to cover a specified area e.g. 1.5 ha of matured cotton. Hence, eliminates the need for measuring, handling and mixing the chemical or for calibrating the sprayer.

The batteries are contained in a plastic tube-handle that carries the bozzle at its end. The energy requirement of the electrodyne system is low, (4) four standard U- 2 batteries can give 60 hrs of use. This will cover a whole season’s needs provided the batteries are kept in a dry place between sprayings. At the end of each roll, turn the bottle into a resting position without turning up the motor. Make the next swath width upwind with the motor still on. The position of the bottle should be vertical and the cloud of droplets must be carried away from handler. However, if yellow nozzle is used 1 litre bottle should be emptied in 25 minutes. i.e. 40 ml/min.

Others: Other sprayers like a tractor mounted equipment are used to apply pesticides, plant growth regulators and foliar nutrients to orchard trees on large area of land. On a less significant scale, other sprayers such as sprayers mounted on tractors or other vehicles in industrial crops, rice, cotton and cowpea production. They deployed different ways of applying powders (i.e. a plastic bottle with holes for post harvest, a hand operated duster and plastic bags containing insecticides) including the use of a fogging machine. Though post harvest application was done by sprinkling pesticides by hand.

2.1 Tasks Associated with the use of Pesticide

Pesticide use is typically associated with three basic stages:

(i) mixing and loading the pesticide product,
(ii) application of the spray solution, and
(iii) clean-up of the spraying equipment.

Mixing and loading are considered the tasks associated with the greatest intensity of pesticide exposure because farmers are exposed to the concentrated product and consequently face high exposure events (e.g., spills). However, the risk from total exposure during pesticide application may exceed that incurred during mixing and loading because pesticide application usually takes more time than the tasks of mixing and loading. Pesticide drift is also a permanent hazard in pesticide use, because it exists even in the most careful applications, and therefore, can increase the possibility of detrimental effects of pesticide use on the users and the environment [17]. There is also evidence that cleaning the equipment after spraying may also be an important source of exposure, which included the level of pesticide exposure to the operator and the type of spraying equipment used. Hand spraying with wide-area spray nozzles is associated with greater exposure to the operator than narrowly focused spray nozzles. The tractor

mounted application equipment is associated with a higher degree of operator exposure than when the spray equipment is attached to a trailer during pesticide application. Pesticide deposition on different parts of the operator's body may vary largely due to differences in individual work rates and habits. Several studies on the contamination of the unprotected body in pesticide applicators showed that the hands and the forearms suffer the greatest pesticide contamination during preparation and application of pesticides. However, other body parts such as the thighs, the forearms, the chest, and the back may also be subjected to major contamination.

Clean-up of the spraying equipment is an important task in the use of pesticides. The time spent on the task of cleaning may take a considerable part of the basic stages of pesticide handling [18,19]. Despite considerable variation among farm workers, equipment cleaning has been found to contribute greatly to workers' daily dermal exposure [18]. Spills and splashes considered insignificant are also a major source of dermal contamination for pesticide applicators, and often the exposure from these events can result in major acute and long-term health effects/challenges [19].This also agreed with the several workers who reported that spills and splashes usually occur during mixing or loading and application, but may also appear in the stage of equipment clean-up [18]. Likewise farmers (or farm workers) who make the spray solutions and apply pesticides including those re-entering the sprayed fields may also face pesticide exposure, sometimes to significant levels [20, 21]. As a result, re-entry farm workers may face even greater exposure than pesticide applicators, probably because of negligent, thus safety training and the use of PPE are usually less, and the duration of exposure may be greater than that of the applicators [20-22]. Therefore, exposures by re-entry in the sprayed fields become a serious problem when farm workers re-enter the treated fields immediately after pesticide application [23]. Spray drift from neighboring fields and overexposure events against each involving groups of farm workers, have been documented as inadvertent events of farmers' exposure to pesticides [24]. Although one of the major problems is that farmers believed that investments in protective clothing, masks or gloves only pay back in terms of health and well being, rather than financial terms. Farmers, who are unaware of the risks of pesticide exposure, aggravated by low income are not likely to pay for such items, especially in cases of scarcity. In the past, irrespective amount of pesticide being applied peasant farmers hardly wear any protective materials in Nigeria [25]. Illiteracy further escalates the problems where farmers can neither read instructions nor cautions on the product label.

2.2 Safety and Effectiveness of Pesticide use

Farmers generally tend to be more generous in the use of pesticides than really needed because of his desires to reduce risks of crop losses. However, the perception by farmers and researchers of yield losses because of pests is usually higher than corresponding actual losses. This brings to bear on the farmer penchant to use large quantities of pesticides that have only marginal or no benefits in terms of yield gains and may even induce pest outbreaks. Nonetheless, in many countries, the overuse of pesticides was being encouraged by the government policy of pesticide subsidies [26]. Pesticides have over the years become more specific and generally less toxic to humans though hardly any pesticide is still harmless to humans. Moreover, many of the unapproved pesticides that are highly or even extremely toxic (WHO, 1992); [27], are still used in developing countries. Ignorance on the side of the farmer brings about health hazards which also contribute to misuse and inefficient application of pesticides. Problems that were mentioned specifically include the inability to identify pests, usage of the wrong type of nozzle, wrongly mixing of pesticides and using ULV formulations for knapsack applications.

ULV applications entail a more `sophisticated' way of applying pesticides that is better handled by experts with required knowledge and skills from the user and also this may increase the risks of contamination. It may not be unconnected with high concentrations of the active ingredient contained in the spray liquid and walking through the spray cloud and the treated foliage easily contaminates the operators' clothes and skin with high doses of pesticide. However, phytotoxicity through overdoses occurs more easily with ULV applications.

Youdeowei [28] reported wrongly application of Gammalin 20 and other pesticides poured into rivers and ponds for killing fish, Rodenticides as baits to kill wildlife like grasscutter and Aerosols including powder formulations applied to preserve dried fish, grains or kolanuts which are

later sold to humans for consumption; and DDT powder and DDVP aerosols applied directly to the heads of humans infested with head lice.

Having knowing what exactly the problems status and solution that would engender improvement of the current practice of pesticide application to increase not only effectiveness but also safety of the user. An increase in effectiveness will also result in a reduction of usage representing a decrease in costs and in environmental hazard. The pesticide use has increased in developing countries ever since its introduction and still next to traditional methods such as tillage, burning and crop rotation, thus represents a vital pest control strategy for farmers in developing countries. However, for intervention of techniques such as Integrated Pest Management and the use of crop varieties with higher resistance, the current growth of pesticide application would have been declined. We can therefore safely state that African agriculture is still dependent on pesticides to attain acceptable levels of crop production. Furthermore pesticides have over the years become more powerful and more specific and therefore demand for a higher standard in application technique. For as long as these two situations prevail it does serve a purpose to make an effort to apply the pesticides needed with an efficiency as high as possible, as safe as possible and with a minimum of environmental hazard. Therefore improving the practice of pesticide application will, through improved efficiency, contribute to the drive to reduce the use of chemicals.

A paradigm shift towards alternative cropping systems that are less dependent on pesticides for the desirable goal of minimum exposure to pesticides is achievable. Similarly, focusing more on ecological approaches of crop protection based on available ecological knowledge. Though, the use of advanced ecological knowledge by agronomists is fairly recent. The purposes of this approach are to increase the abilities of agricultural systems to induce the natural processes of pest regulation and to contribute to the improvement of the agricultural production. Consequently, sustainable systems of pest, disease, and weed management should include prevention, decision making, and control [29]. According to Ratnadass, [30] who reported that prevention can be optimized by maximizing the use of natural processes in the cropping system, suppressing the harmful organisms by promoting the development of antagonists, optimizing the diversity of the system, and stimulating the recycling of internal resources. Therefore, instruments to achieve that may include: (i) farm hygiene with the important element of the use of clean seed or planting material and maintaining temporal and spatial separation between crops of the same species (e.g., control of volunteers), (ii) synergistic and antagonistic effects occurring in a cropping system, e.g., the suppression of diseases and pests by a designed system of non-chemical preventive methods, including the cultivation of catch crops and the use of soil amendments to enhance populations of antagonists, (iii) cultural practices that support ecological processes, such as delayed planting to reduce weed growth or even prevent seed set, removal of crop residues or plant debris, management of soil organic matter, and soil tillage strategies, (iv) optimization of other inputs such that a crop can grow in a healthy condition that will assist in withstanding attacks of pathogens or that will increase the damage threshold, (v) breeding for tolerance, e.g., by selecting for specific plant types that are more competitive against weeds or resistant to diseases, e.g., against blights.

2.3 Effects of the Pesticide Application on Agricultural Productivity

The current low level of crop protection on the farm level is attributed to inadequate required equipment and pesticides and hence unavailable pesticide is considered as a major constraint to effective pest control. The advantage of knock down effect of pesticide that gave rapid effectiveness during sudden pest population increases is defeated due to limited infrastructure and an inefficient supply chain of pesticides that are not present when needed. Another major problem is poor maintenance culture for rarely available application equipment. Obviously a breakdown of spraying equipment at the time when it is needed, can lead to disaster in pest outbreak situations which is mostly the time when farmers usually observed that the equipment is faulty. From the foregoing, it is likely that farmers will increase the use of pesticides on their farms if they have the wherewithal including finance to do so.

Sometimes, the equipment available is defective or simply not appropriate and associated problem is that knapsack sprayers need considerable amounts of water per ha. For example, when a volume of 200 litres/ha is used, this requires some 10 head loads of 20 litres over distances of up to 1 km, which will involve over 6

man-hours effort. In most cases clean water may simply not be available and in many areas of the tropics, especially in the drier savannah areas, water remains the most crucial constraint to crop protection.

However, farmers in the field are often unaware that pesticides should be used in a specific dosage in order to be as cost-effective as possible. Furthermore, the unavailability of measuring instruments, illiteracy of farmers and non-calibrated equipment remain a big challenge. Therefore, the correct concentration of the pesticide in the spraying liquid was achieved through the supply of pesticides in sachets containing sufficient for each knapsack load, as being practised in Central Africa. The system proved to be remarkably successful and durable for farmers who could obtain water [31].

Farmers would incur more financial losses from overdose use of pesticides which may be wasteful and resorted to phytotoxicity that might decrease yields. The biggest risk however, of overdose and under dose is the increased likelihood for the development of resistance against pesticides, which can have devastating large-scale effects on crop production. Consequently, a long-term program utilizing IPM concepts has been introduced using resistant varieties, biological control, improved agricultural practices, and more judicious use of pesticides.

2.4 Poor Handling of Equipment

The major mismanagement of equipment is lack of maintenance culture and negligent on the part of the farmers. Peasant farmers are fond of incorrect handling, off-season storage that damages the equipment, leaving mixed pesticides in the sprayer overnight, damaging the disc of spinning disc sprayers and also occasionally damage nozzles by enlarging the hole to increase the flow. The combination of glaring mismanagement and carefree attitude towards maintenance culture put pesticide application equipment in West-Africa in a bad state. The lack of maintenance stemmed from two important shortages of spare parts (either unavailability or unaffordability) and specialists to repair and maintain the equipment. The latter implies that the specialists (specialized mechanics) working in the field would repair and maintain the application equipment rather than by the farmers themselves. The equipment available at the village level is usually the cheapest and least durable. The enthusiastic farmer may persevere and improvise repairs, but as appropriate spare parts are seldom available, might be discouraged and abandon further attempts to improve their pest control.

A major cause of poisoning when using a knapsack sprayer, is the spilling of pesticides over the back of the operator because of a faulty locking cap of the container. Cracks and leaks in application containers and in over aged rubber hoses, and worn out or loosen washers are a great cause for leakages that often poison the user. This responsible for waste of pesticides, environmental pollution and phyto-toxicity where pesticides fall on the crop in high doses. Even when sprayers are working correctly, they will still need to be calibrated, especially in cases where the same nozzles are used for extensive periods of time. Although practised and taught in research and training institutes, the results show that calibration is hardly ever done in practice, resulting in incorrect dosage.

2.5 Environmental and Health Hazards

The environmental hazards that can result from pesticide use are only fairly recently known in the temperate world but far less is known about transport and fate of pesticides in the water and soil of desert and tropical areas. It is only poor comfort that most toxic and persistent pesticides that build up in the food chains are now banned. Pesticides have over the years become more specific and less toxic but environmental pollution still exists but the extent varied.

Fortunately it is generally believed that not only the present trend for a slowing down in the overall growth rate of chemical pesticide use will pursue but also that a combination of greater emphasis on Integrated Pest Management (IPM) and biological control methods in general, and concerns about public health risks and ecosystem protection, will reduce both the rates of application and the environmental risks per unit of pesticide use [26].

Wrong protocol and procedure in the pesticide application attributes greatly to the environmental hazard caused by pesticide use. The inherent hazard can never be eradicated due to the nature of the pesticide but only by improving the situation, ranging from using better and properly functioning application equipment to training farmers to minimize the damage.

The decrease in yields and annual production pointed in direction of the final and main negative consequence of the shortcomings in today's crop protection practice. Conclusively, farmers and other farm workers generally lack the means to efficiently protect their crops against pests. Either the machinery or pesticides are not at their disposal to do it, or due to faulty equipment, lack of training and knowledge which impacted on the treatment done ineffectively, untimely and at high costs.

2.6 Government Intervention and Research Policy

In the regulation of pesticide application, government bodies have an explicit role to play because both producers and users are not likely to limit themselves in the sales and use of pesticides. They are not likely to be `self-regulating' in terms of minimizing health and environmental hazards, since this, in most cases, represents extra costs and no visible, short term profits. The agro chemical business in developing countries e.g. Nigeria is not adequately coordinated, as a result a lot of malpractices are going on in the process of its fragmented and unorganized marketing and distribution. The resultant effect of such lapses include; counterfeiting and faking recycling of old stocks, manufacturing of empty plastic containers to market adulterated agrochemicals, which are sold at reduced prices and lack of disposal facilities [32,33]. However, representatives of distributorship company dealing in pesticides and equipment in Senegal are saddled with the responsibility to instruct farmers on the use of application equipment and on safety precautions. This is a major step forward if not only distributors and retailers but also the producers would take on these responsibilities, though this is contradictory to their natural desire to increase turnover.

According to Youdeowei, [8] reported that the effective control of pesticides in the West-African sub-region remains poor and seriously hampered by several factors including: Lack of proper legislative authority; shortage of trained personnel in pesticide regulatory procedures; lack of infrastructure, transportation, equipment and materials; very low budgetary allocation of operating funds and lack of formulation control and pesticide residue analysis facilities and capabilities.

There are noted weaknesses in the abilities of the government-designated authorities to enforce approved regulatory procedures that are fully exploited by producers of pesticides. Some of them export products to these countries in containers that are inadequately or wrongly labeled intentionally and in total disregard of the international guidelines approved for labeling and marketing pesticides. FAO has elaborated an International Code of Conduct on the Distribution and Use of Pesticides that should avoid these practices. The document sets forth and establishes voluntary standards of conduct for all public and private entities engaged in or affecting the distribution and use of pesticides. Although this is not legally binding, it is becoming increasingly mandatory.

In the ideal situation, governments should regulate and control the use of pesticides but leave the actual trade and importation of pesticides and equipment to the private sector. Unfortunately, in many African countries, the Government, through the Ministry of Agriculture, still remain importer of pesticides. As it is often the Crop Protection Service of the same Ministry of Agriculture that is regulating pesticide use, the implication is that the Ministry is regulating itself. This issue has been resolved in Ghana and Nigeria by the creation of bodies outside the Ministry of Agriculture. In Ghana this is the Environmental Protection Council and in Nigeria it is the Food and Drugs Administration and Control Department of the Ministry of Health [28]. Presently, there is neither any detailed research on environmental impact of pesticides in Nigeria nor any monitoring process in place. The only form of regulation involves the registration of brands of agro-chemicals by the National Agency for Food and Drug Administration and Control (NAFDAC) and screening cum recommendation of pesticide formulations and spraying equipment for cocoa by CRIN. The procedures are to ensure that substandard products are not marketed in Nigeria and to confirm the efficacy of formulations offered for cocoa pests control. However, there is need for the regulatory agencies to contain the sale of substandard pesticides for cocoa as well as other crops in Nigeria.

Pesticides remain a tool for modern agriculture, so it is important to design strategies that will reduce pesticide impact [34]. This can be achieved with minimum use of pesticides using accurate diagnosis and advanced knowledge of pest problems, optimized timing of interventions for maximum long-term efficiency, selection of a pesticide product with minimum impact on non-

target organisms and the operator, and improved application of the selected product for maximum dose transfer to the biological target [35]. The overall optimization of the procedure of pesticide handling, strictly following the regulations and taking into account the public concerns with reference to pesticide residues in food and drinking water are essential. Whenever pesticides are however used, operative and well-maintained spraying equipment and the necessary precautions at all stages of pesticide handling are essential for reducing farmers' exposure to pesticides.

Quality control of pesticides is generally non-existent and farmers in developing countries can normally buy whatever is available on the global market. In practice this means that registration of pesticides is mostly based on the results of quality control and research carried out in the industrialized countries with temperate climates, which does not automatically qualify pesticides for use in the tropics. Additionally there are cases where countries allow or cannot prevent the use of pesticides that are generally banned elsewhere.

Concerning testing and controlling import and use of pesticide application equipment, Nigeria seems to be most advanced whereas it evaluates different types of equipment on a national level. Most countries reported no national control measures over the type and quality of equipment being used. This control is rather ad hoc and scattered over various institutions and agency. In some countries, like Burkina Faso, specialized teams that visit farmers carry out pesticide control. These teams do carry equipment that has been tested and evaluated. In general the regulations and control over the use of pesticides and the quality of the equipment leaves too many gaps. The result of this on the farm level is misuse and inappropriate use of pesticides with equipment that does not meet the minimum of quality standards. Next to health and environmental hazards this leads to waste of expensive pesticides, resistance of pests and decreased yields.

2.7 Maintenance of Spraying Equipment

Insecticides, liming and nematicides containing spraying equipment should be properly cleansed after use.

WP – Rinse with water containing wetting agent and detergent, then rinse with clean water

EC – Flush with water and detergent; keep agitated on flush again with water and drain. Dismantle/open knapsack and mistblow and turn over the barrel to dry. Solutions – Rinse as for EC and drain to dry.

At the end of every farming activity, the whole machine should be cleansed with kerosene and stored in a dry place.

3. GENERAL SAFETY FOR THE USERS

Personal protective equipment (PPE) are of various types and these include gloves, boots, hats, long sleeve shirts, and chemical-resistant coveralls used in pesticide handling to limit dermal exposure. The toxicity of the pesticide that necessitated circumstances of exposure, and the worker's personal preferences ultimately affect the type of PPE used among farmers. The use of gloves and boots are the minimum PPE for most pesticide products. As a general rule, highly toxic pesticides require the use of multiple types of PPE for reducing exposure. Different types of PPE provide complementary levels of personal protection against dermal exposure. Thus the PPE provides protection that may vary according to the protective features of each type of PPE itself, the way in which the pesticide is applied, and the level of correct fitting and maintenance by the farmers. Common protective clothing provides protection against exposure according to fabric type, including thickness and weight. Garments of both barrier and non-barrier fabrics were found to decrease dermal exposure [36]; however, greater protection was found by waterproof polypropylene fabrics compared with cotton garments [37]. Penetration through cotton clothing ranged from 11.2% to 26.8%, whereas in the case of synthetic material, penetration was found to be less than 2.4% [38]. The effectiveness of PPE in terms of pesticide penetration through clothing has been reported to be affected by the application method [39-41]; however, results concerning this issue have been inconsistent. For example, while low-pressure backpack spraying was associated with greater pesticide penetration through the clothing than high-pressure spraying [42], according to other research [38], a low-pressure backpack application resulted in lower penetration than high-pressure hand lance spraying.

An important determinant of the effectiveness of any PPE, which often gets unnoticed, is the way in which each PPE is actually used. Often, farmers' movements during pesticide application that promote the relocation and further spread of

dust or liquids via PPE fabric along with farmers' sweating, particularly in hot environments, also affect penetration resistance of the PPE fabric [43]. Parts of a polyethylene coverall showed greater penetration, taking into account that the movement of farmers is likely to create friction [44]. Obviously, the protective ability of any PPE depends on proper use. For example, farmers who often roll sleeves up or take gloves off in the middle of pesticide handling are at increased risk of dermal exposure [38]. Personal protection can be low because the PPE is unsuitable, incorrectly fitted, not properly maintained, and improperly used. Thus, the theoretically maximum levels of protection are seldom achieved with routinely use of PPE, and the actual level of personal protection is difficult to assess. These are the other safety protocols to observe by the users:

(1) Operators in a glasshouse using concentrates, aerosols should be fully covered – hood, coveralls rubber gloves and washable boots (rubber cut shoe or boots); full face mask equipped with canister and fitter, similar to goggles and a fitting cap worn by farmers.
(2) Tree crop sprayers outdoor – Rain hat or hood (women night caps will do for economic purposes or at worst local caps) rain coat, washable gloves and shoes. He can substitute a handkerchief tied over nose and mouth for respirator or gas mask.
(3) When handling the pesticides farmers should wear over-all and jackboots that cover every part of the body. They should avoid contact with skin, eyes and excessive inhalation. Again, spraying should not be done in the direction of wind or unfavourable climatic condition.

3.1 Farm Precaution

A. Selecting pesticides

i. Select a pesticide recommended for a specific use by a competent authority eg specialist, Agric agent or adviser
ii. Select a formulation that is effective against the pest to be controlled and suited for safe application with the equipment available
iii. In choice situation, use the spray before dust to reduce drift hazards; the average particle of dust is smaller than that of most sprays, dusts tend to drift considerably faster than sprays
iv. Select granules in preference to spray or dust, if found as effective and economical. However, they persist longer in soil than other forms of the same material.
v. Where possible purchase WP, EC or dusts in containers of such a size that one or more containers can be entirely used for each tank charge or area to be covered e.g 1l or 0.5l/1kg or 0.5kg pack. To eliminate the hazard of handling and storing partly filled containers
vi. In choice situation of formulation consider the relative hazards
   (a) An oil soluble formulation is usually more hazardous to operators than water soluble formulation. Thus, it is more easily absorbed through the skin
   (b) Formulation that are not completely soluble are less hazardous than water soluble or oil soluble formulations

B. Storing Pesticides

(i) Store pesticides in their original container, hence never transfer pesticide to another water, food or beverage containers
(ii) Adhere to the instructions and see that the labels remain on containers, in storage
(iii) Store pesticides in a dry place and out of the reach of the children, animals or unauthorized person
(iv) Never store both poisonous and harmless chemicals in the same place, particularly if they are similar formulations of EC or WP
(v) Do not store herbicides and defoliators near insecticides to avoid cross contamination
(vi) Remove from storage only the amount of material needed for a day application
(vii) Store and label unused pesticides
(viii) Do not burn container (pesticide) even after use
(ix) The containers should be properly washed before pouring chemical for use
(x) The pesticide container (bottles) should not be used for domestic purposes
(xi) Do not burn pressurized containers, to avoid explosion and spilling of remnants on handler.

C. Disposal of Empty container and unwanted pesticides

Do not save/keep or re-use empty pesticide containers, hence dispose pesticides by

(i) Pouring into a hole dug
(ii) Avoiding taking into incinerator

Ways of disposing empty containers of used pesticides

(i) Before disposing of large containers, empty pesticide remnants into a pit dug in sandy soil away from water sources. Rinse containers with water after use. Punch the containers to discourage future or domestic use
(ii) Do not convert empty drums or barrels into domestic use, livestock feed troughs, water storage tanks or raft floaters. They would be sources of feed or water contamination
(iii) Find a private disposal site created specifically for dumping empty containers and unwanted pesticides; a site away from home and farm, streams, ponds, pasture, and away from watershed of a public or private water supply
(iv) Bury small containers about 60 m, crush glass container, remove all caps or lids
(v) Burn containers if there is no reliable instruction on the label, except herbicides container.
(vi) Pesticides (glass) (metal) should be punched or crushed, and bury deep in the soil Destroy empty containers after use

3.2 First Aid Treatment

(i) Induce vomiting by giving victim a table spoon of salt in a glass of warm water. Repeat treatment until vomit fluid is clear. Then take the victim to a physician, let victim lie down in transit
(ii) Do not induce vomiting only, give victim large quantities of milk or eggs white sliced in water. Then take the victim to the doctor
(iii) If clothing is being contaminated remove the clothing and wash the subject skin thoroughly with soap and water; thus flush the skin with plenty of water
(iv) If chemical has been inhaled get the victim into fresh air immediately, if his breathing has stopped apply artificial respiration or seek for medical attention
(v) If the chemical make contact with the eyes, flush the eyes with plenty of water for at least 5 mins. Get medical attention immediately.

3.3 Mixing Pesticides

Read the label carefully and follow the directions exactly. Mix pesticides carefully and accurately, using only the recommended amount. Firstly, pesticide containers are opened during mixing, and pesticide formulations are usually highly concentrated. Open liquids on a level surface and below eye level to avoid spilling and splashing. Pour liquids below eye level and as close to ground as possible. Do not try to pour from a container that is too heavy. Open powders with scissors to avoid spreading dust. Use the proper measuring tools when mixing pesticides. Mix pesticides outdoors or in a well-lit and ventilated area. Secondly, people who work with pesticides tend to be less safety conscious when they are mixing pesticides than when they are actually spraying them. However, people climb on equipment carrying pesticides, lift and pour open containers of pesticide, and often work alone with pesticides; all of which can be dangerous.

3.4 Mixing and Handling Pesticide

(i) This should be done in the open or in a well ventilated place to avoid chocking and poisoning through inhalation. Also volatile liquids may cause fires or explosions
(ii) Open pesticide containers carefully to prevent blowing of dusts or splashing of liquids
(iii) Pour pesticide carefully to avoid spilling. To achieve this hold the container from which you are pouring close to the receiving container
(iv) Use special containers, drums or pails for mixing pesticides; for safety attach a tag of red tape or electric cable to distinguish from others used for domestic purposes. Never use food or beverage containers
(v) As the motor mechanic do, never use your mouth to siphon a pesticide from a container (though some farmers use pesticides to treat sores warms – Dangerous !! or blow nozzles with mouth before washing.
(vi) Do not mix pesticide concentration higher than those recommended. Measure accurately to ensure accurate correct and safe dosage, and avoid wastage.
(vii) Avoid spilling concentrates on skin or clothes. Keep hands away from the face, head and neck when mixing. Keep away from eyes , mouth and nose; wash any spill on body with water and soap.

Change contaminated clothes and sander before wearing again

(viii) If pesticides get into the eyes flush the eyes for over 5 mins then call a physician

(ix) If swallowed apply first aid as stated above though it may not possible in a panicky situation. Rush to a hospital. Telephone in and same where applicable.

(x) Wear gloves, splash-proof goggles or face shield, and other required personal protective clothing. Wear rubber gloves and other protective clothing. Rinse gloves well with water before removing then. Do not turn gloves inside out when removing, wash hands up to elbow immediately after.

(xi) In case of fumigants, WP and dusts wear nose and mouth canister and clothing for the body. Simple cotton long sleeve short and trouser will do

(xii) Avoid smoking, eating, drinking and snuff when mixing and apply pesticides

(xiii) Do not spray pesticide against wind direction.

(xiv) Use dust pesticide in morning.

(xv) Avoid the use of extremely toxic pesticide in apiculture areas.

(xvi) Be aware with Government guideline about the banned and restricted pesticide.

4. CONCLUSION

Low level of awareness of crop protection generally affects effectively protection of the crops against the number one constraint (pests) of increased production. An increased availability and affordability of both sprayers and pesticides would improve the situation, whereas the malpractice in pesticide application and the bad state of the equipment could hinder an effective application.

Specific equipment related problems included leaks in containers and hoses and faulty locking caps that directly spilled and contaminated the user. Though damaged or purposely enlarged nozzles seriously hamper effective pest control and continued use might raise the cost of pesticide application, thus there is need for calibration to avoid incorrect dosage. Spinning disc sprayers may partly solve some of these problems being of a less complex technology, but risks of intoxication may increase. There is a further need to enlighten farmers on safety aspects, equipment issues, calibration, spraying techniques including the necessity for the use of protective clothing, gloves and masks with pesticides.

Farmers seemingly unwilling to invest in items (protective materials) that only protect their health but give no financial return. Though, farmers that are not fully aware of the hazards of pesticide contamination are not likely to make this investment. Both producers and users are not likely to regulate themselves neither in the sale and use of pesticides, nor in minimizing health and environmental hazards. This makes the need for government entities intervention indispensable to play a regulatory role.

Farmers lack the means to efficiently protect their crops against pest which is responsible for the problem of health and environmental hazards. The paradigm shift to reduce pesticide use through systems like IPM and biological control needs to be encouraged and cannot be underestimated. However, the use of pesticides is likely to show a moderate increase for some years to come and this aligns with the need for improved crop protection in a world with ever expanding needs for food. The drive to reduce pesticide use should be faced realistically squarely beyond lip services to promote safe, effective and timely application of pesticides in agricultural activities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Woodruff TJ Kyle, Bois AD, FY, Evaluating health risks from occupational exposure to pesticides and the regulatory response. Environ. Health Perspect. 1994;102:1088–1096.
[Google Scholar] [CrossRef] [PubMed]

2. Maroni M. Fait, Colosio AC. Risk assessment and management of occupational exposure to pesticides. Toxicol. Lett. 1999;107:145–153.
[Google Scholar] [CrossRef]

3. Ye M, Beach J, Martin JW, Senthilselvan A. Occupational pesticide exposure and respiratory health. Int. J. Environ. Res. Public Health. 2013;10:6442–6471.
[Google Scholar] [CrossRef] [PubMed]

4. Glass CR, Machera K. Evaluating the risks of occupational pesticide exposure. Hell. Plant Prot. J. 2009;2:1–9.
[Google Scholar]
5. Lale NSE. An overview of the use of plant products in the management of stored products. Coleoptera in the tropics post harvest News and information. 1995;6:69N- 75N.
6. Adedire CO, Ajayi TS. Assessment of the insecticidal properties of some plant extracts as grain protectants against the maize weevil, Sitophilus zeamais Motschulsky. Nigerian Journal of Entomology. 2011;13:93-101.
7. Ecobichon DJ. Pesticide use in developing countries. Toxicology 2001;160:27–33.
[Google Scholar] [CrossRef]
8. Aktar MW, Sengupta D, Chowdhury A. Impact of pesticides use in agriculture: Their benefits and hazards. Interdisc. Toxicol. 2009;2:1–12.
[Google Scholar] [CrossRef] [PubMed]
9. Zhang C, Hu R, Shi G, Jin Y, Robson MG, Huang X. Overuse or underuse? An observation of pesticide use in China. Sci. Total Environ. 2015;538:1–6.
[Google Scholar] [CrossRef] [PubMed]
10. Robertson A, Tirado C, Lobstein T, Jermini M, Knai C, Jensen JH, Ferro-Luzzi A, James WPT. Food and Health in Europe: A New Basis for Action, European Series, No. 96 WHO Regional Publications: Geneva, Switzerland. 2004; 385.
[Google Scholar]
11. Calvert GM, Karnik J, Mehler L, Beckman J, Morrissey B, Sievert J, Barrett R, Lackovic M, Mabee L, Schwartz A, Mitchell Y, Moraga-McHaley S. Acute pesticide poisoning among agricultural workers in the United States, 1998–2005. Am. J. Ind. Med. 2008;51:883–898.
[Google Scholar] [CrossRef] [PubMed]
12. Matthews GA, de Schaetzen N, John F. Tunnel spraying: an environmentally favourable approach for pesticide application in orchards. Pesticide Outlook. 1992;3:13-16.
13. van Emden HF, Peakall DB. Beyond Silent Spring Chapman and HaillUNEP, London; 1996.
14. Butler Ellis MC, Tuck CR, Miller PCH. The effect of some adjuvants on sprays produced by agricultural flat fan nozzles. Crop Protection. 1997;16:41-50.
15. Knowles DA. Chemistry and Technology of Agrochemical Formulations© Kluwer Academic, Publishers; 1998.
16. Asogwa EU, Dongo LN. Problems associated with pesticide usage and application in Nigerian cocoa production: a review. African Journal of Agricultural Research. 2009;4(8):675-683.
17. Damalas CA. Pesticide drift: Seeking reliable environmental indicators of exposure assessment. In Environmental Indicators Armon, R., Hänninen, O., Eds. Springer: Dordrecht, Netherlands. 2015:;251–261.
[Google Scholar]
18. Lebailly P, Bouchart V, Baldi I, Lecluse Y, Heutte N, Gislard A, Malas J-P. Exposure to pesticides in open-field farming in France. Ann. Occup. Hyg. 2009;53:69–81.
[Google Scholar] [CrossRef] [PubMed]
19. Alavanja MC, Sprince NL, Oliver E, Whitten P, Lynch, C.F. Gillette, P.P. Logsden-Sacket, N. Zwerling, C. Nested case-control analysis of high pesticide exposure events from the Agricultural Health Study. Am. J. Ind. Med. 2001;39:557–563.
[Google Scholar] [CrossRef] [PubMed]
20. Coronado GD, Thompson B, Strong L, Griffith WC, Islas I. Agricultural task and exposure to organophosphate pesticides among farmworkers. Environ. Health Perspect. 2004;112:142–147.
[Google Scholar] [CrossRef]
21. Strong LL, Thompson B, Coronado GD, Griffith WC, Vigoren EM, Islas I. Health symptoms and exposure to organophosphate pesticides in farmworkers. Am. J. Ind. Med. 2004;46:599–606.
[Google Scholar] [CrossRef] [PubMed]
22. Ward MH, Prince JR, Stewart PA, Zahm SH. Determining the probability of pesticide exposures among migrant farmworkers: Results from a feasibility study. Am. J. Ind. Med. 2001;40:538–553.
[Google Scholar] [CrossRef] [PubMed]
23. Burns C, Mahlburg W, Dutra JPJ. Pesticide exposure among farm workers. Environ. Res. 2007;105:285–288.
[Google Scholar] [CrossRef] [PubMed]
24. Cunha JP, Chueca P, Garcerá C, Moltó E. Risk assessment of pesticide spray drift from citrus applications with air-blast sprayers in Spain. Crop Prot. 2012;116:116–123.
[Google Scholar] [CrossRef]

25. Meijde, Gvan der Pesticide Application Techniques in Africa. A study by the Agricultural Engineering Branch of through the FAO Regional Office for Africa. 1998;17.
26. Alexandratos World agriculture: Towards 2010, An FAO Study Food and Agriculture Organization of the United Nations, Rome; 1995.
27. Friedrich T. Agricultural Pesticide Application FAO Agricultural Engineering Branch AGSE, FAO, Rome; 1996.
28. Youdeowei A. Provisional report on pesticide management in Anglophone West Africa prepared for FAO Rome; 1989.
29. Struik PC, Kropff MJ. An agricultural vision. In Pesticides: Problems, Improvements, Alternatives den Hond, F., Groenewegen, P., van Straalen, N., Eds. Blackwell Science: Oxford, UK. 2003;16–30.
[Google Scholar]
30. Ratnadass A, Fernandes P, Avelino J, Habib R. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: A review. Agron. Sustain. Dev. 2012;32:273–303.
[Google Scholar] [CrossRef][Green Version]
31. Matthews GA. The integration of new technology in pesticide application systems for small-scale farmers in the tropics in: Marini Bettolo G.B. (ed.) (1987) Towards a second green revolution. 1987;331-336.
32. Edache OA. Pesticde usage in crop production. Paper presented at the National Programme on Agrochemical Technology. University of Agriculture, Markudi, July 26-29. 1998;16.
33. Oduwole OO. Sustainable cocoa production in Nigeria: Fan perception of technology characteristics and socio economic factors in adoption decision. Proc. 13th Int. Cocoa Res. Conf. 2001;1147-1152.
34. Ekström G, Ekbom B. Pest control in agro-ecosystems: An ecological approach. Crit. Rev. Plant Sci. 2011;30:74–94.
[Google Scholar] [CrossRef]
35. Dent D. Overview of agrobiologicals and alternatives to synthetic pesticides. In The Pesticide Detox: Towards a More Sustainable Agriculture Pretty, J., Ed. Earthscan: London, UK. 2005;70–82.
[Google Scholar]
36. Coffman CW, Stone J, Slocum AC, Landers AJ, Schwab CV, Olsen LG, Lee S. Use of engineering controls and personal protective equipment by certified pesticide applicators. J. Agric. Saf. Health. 2009;15:311–326.
[Google Scholar] [CrossRef] [PubMed]
37. Aprea C, Terenzoni B, De Angelis V, Sciarra G, Lunghini L, Borzacchi G,. Evaluation of skin and respiratory doses and urinary excretion of alkylphosphates in workers exposed to dimethoate during treatment of olive trees. Arch. Environ. Contam. Toxicol. 2004;48:127–134.
[Google Scholar] [CrossRef] [PubMed]
38. Vitali M, Protano C, Del Monte A, Ensabella F, Guidotti M. Operative modalities and exposure to pesticides during open field treatments among a group of agricultural subcontractors. Arch. Environ. Contam. Toxicol. 2009;57:193–202.
[Google Scholar] [CrossRef] [PubMed]
39. Keifer MC. Effectiveness of interventions in reducing pesticide overexposure and poisonings. Am. J. Prev. Med. 2000;18:80–89.
[Google Scholar] [CrossRef]
40. Driver J, Ross J, Mihlan G, Lunchick C. Landenberger B. Derivation of single layer clothing penetration factors from the pesticide handlers exposure database. Regul. Toxicol. Pharmacol. 2007;49:125–137.
[Google Scholar] [CrossRef] [PubMed]
41. Nigg HN, Stamper JH, Easter E, DeJonge JO. Protection afforded greenhouse pesticide applicators by coveralls: A field test. Arch. Environ. Contam. Toxicol. 1993;25:529–533.
[Google Scholar] [CrossRef] [PubMed]
42. Stewart PA, Fears T, Kross B, Ogilvie L, Blair A. Exposure of farmers to phosmet, a swine insecticide. Scand. J. Work Environ. Health 1999;25:33–38.
[Google Scholar] [CrossRef] [PubMed]
43. Fenske RA, Birnbaum SG, Methner MM, Lu C, Nigg HN. Fluorescent tracer evaluation of chemical protective clothing during pesticide applications in central Florida citrus groves. J. Agric. Saf. Health. 2002;8:319–331.
[Google Scholar] [CrossRef] [PubMed]
44. Machera K, Goumenou M, Kapetanakis E, Kalamarakis A, Glass CR. Determination of potential dermal and inhalation operator

exposure to malathion in greenhouses with the whole body dosimetry method. Ann. Occup. Hyg. 2003;47:61–70.
[Google Scholar] [CrossRef] [PubMed]

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