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# Pesticides: The Negative Effects, Driving Factors and Management Strategies in Agriculture

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**ABSTRACT**

Pesticides are widely used compounds against pest in agriculture. Although chemical pesticides had made a great contribution to the fight against pests and diseases, nowadays, their indiscriminate use are posing serious ecological consequences. The present review highlights the side effect, accelerating factors, and management strategies of pesticide use on environmental constituents. Pesticides cause serious hazards to agricultural environment and human health as a lot of them and their derivatives remain in the environmental system for a considerable period. Most of them have adverse effects on soil and soil microbes, beneficial organisms and species diversity, fresh water community, water quality and air ecosystem, human health, and sustainable pest management. Moreover, pesticides cause imbalance of biodiversity which directly affects agricultural productivity and/or crop yield. On the other hand, increasing world population, repeated use of persistent and non-biodegradable pesticides, and lack of judicious pesticide usage, weak linkage among stock holders and weak pesticide governance are among factors which contribute in acceleration of ecological impact of pesticides. Hence, proper utilization or effective management of pesticides is compulsory to protect our environment and eventually health hazards associated with it. Adoption of alternative pest control options like integrated pest management, appropriate agronomic practices, resistant/tolerant varieties, bio-control, natural substances, and safe application of minimal toxic synthetic pesticides as a last resort are key measures to mitigate the risk. Likewise, there is a need for more awareness rising among farmers, distributors, industry, policymakers, and other stakeholders in the judicious and discriminate use of pesticides which is critical to reducing the side effects on humans and the environment. Furthermore, activities that increase environmental awareness and safety of pesticides should be initiated by the agrochemical firms and governments.

**Keywords:** Agriculture, environmental impact, Agro-pesticide, risk management

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## 1. Introduction

Pesticides represent widely used chemical substances in agriculture to increase production and quality through controlling pests and pest related diseases. Pesticides are the important agrochemicals used in agricultural system for protection of crops from pests, and can be grouped as herbicides, insecticides, fungicides, rodenticides, nematicides and etc., according to types of pests which they control. According to Narita et al. (2014) [78] and Jallow et al. (2017) [54] pesticides are a vital component and an integral part of modern agriculture. They are used to protect crops and livestock from various pests, diseases, competition from weeds and parasites, thus contributing to increased agricultural production [33,124]. Global pesticide use has grown over the past 20 years to 3.5 billion kg active ingredients per year, amounting to a global market worth $45 billion [86]. Herbicides account for 42%, insecticides 27%, fungicides 22% and disinfectants and other agrochemicals 9% of global pesticide sales. About 2.5 million tonnes (five billion pounds) of pesticides are used each year [2]. On the other hand, the percentage and /or amount of pesticides consumed may vary from country to country, and even different from one locality to others within country due to various factors. Interestingly, the amount of pesticide consumed in crop production system varies based on type and variety of crops. Furthermore, pesticide use intensity is highest in vegetable, fruit and cotton production.

Damalas *et al*. (2017) [22] highlighted that pesticides quickly gained great popularity as an efficient, labor-saving, and economic tool in pest management in most agricultural sectors. In other words, the most frequent method of managing pests and diseases in most agricultural sectors is through the application of pesticides [39]. Farmers depend heavily on pesticides Schreinemachers *et al* (2017) [106], though several alternative strategies for pest management continue to evolve (Fishel, 2007) [34]. However, the prolonged intensive and indiscriminate use of agrochemicals adversely affected the soil biodiversity, agricultural sustainability, and food safety, bringing in long-term harmful effects on nutritional security, human and animal health [88,71]. Most of the agrochemicals negatively affect soil microbial functions and biochemical processes. The alteration in diversity and composition of the beneficial microbial community can be unfavorable to plant growth and development either by reducing nutrient availability or by increasing disease incidence. According to Selcen *et al*. (2017) [105] as widely used agricultural chemical, pesticides are main source of air, water and soil pollution. They are also significant risk factors on human life not only effects on health as a result of misuse or accident, but also via leave a lasting harmful chemicals into the environment.

Despite the importance of pesticides and their wide use throughout the world, nowadays their side effects on environment, human health and non-target or beneficiary organisms continue to become a major problem in the world, especially in developing nations. As suggested in many studies a lot of factors could be contributed to these serious negative consequences associated with agro-pesticides though a little effort has been done to manage this risk. On the other hand, seeking for up to date information and identification of gaps concerning to agro-pesticides and their usage is the key primary activities to improve their management and reduce associated risk. Thus, the aim of this article was to review the pesticides use risk, driving factors and management strategies in agriculture.

## 2. Impacts of Pesticides

Pesticides can pose a negative side effect on human and environment (eco-systems). Although, pesticides were used initially to benefit human life through increase in agricultural productivity and by controlling infectious disease, their adverse effects have overweighed the benefits associated with their use (Gill and Garg, 2014). It has been estimated that only

about 0.1% pesticides reach the target organisms and the remaining applied pesticides contaminates the surrounding environment [13]. Concerns due to risks of non-target impacts of pesticides is increasing globally as shown by increasingly more stringent standards on pesticide residue levels (Macharia et al., 2009) [64]. Pesticides cause: acute and chronic human health effects, contamination of atmospheric, ground and surface water [49,75,67,105]. All creatures, humans and the environment are at risk of adverse effects of pesticides but especially agricultural workers and family members of pesticide applicators have the highest risk of exposure (Bradman et al., 2009) [12]. In this section, the most significant ecological impacts of pesticides in agricultural ecosystems have been discussed.

### 2.1. Impacts on soil and soil microbes

Most of agro-pesticide, especially herbicides are applied to the soil, and they pose paramount effect on the soil and soil microbes. Gill and Garg (2014) reported that a major fraction of the pesticides that are used for agriculture and other purposes accumulates in the soil. The authors also pointed out that indiscriminate and repeated use of pesticides further aggravates this soil accumulation problem. Several factors such as soil properties and soil micro-flora determine the fate of applied pesticides, owing to which it undergoes a variety of degradation, transport, and adsorption/desorption processes (Weber et al., 2004; Labs et al., 2007; Hussain et al., 2009) . The degraded pesticides interact with the soil and with its indigenous microorganisms (Mehjin et al., 2019; Munoz-Leoz et al., 2011) [71,]. According to Khalil et al. (2011) [57] many of the chemicals used in pesticides are persistent soil contaminants, whose impact may endure for decades and adversely affect soil conservation. On the other hand, Johnson (1986) reported that not using the chemicals results in higher soil quality with the additional effect that more organic matter in the soil allows for higher water retention. This helps increase yields for farms in drought years, when organic farms have had yields 20-40% higher than their conventional counterparts. A smaller content of organic matter in the soil increases the amount of pesticide that will leave the area of application, because organic matter binds to and helps break down pesticides (Lotter, et al, 2003) .

Generally, the type and nature of the chemical pesticides determine the level of their adverse effect on soil and/or soil environment. Different chemical can influence the soil and soil microbes in various ways (Table 1) below. For example herbicides can reduce vegetative cover of the ground, thus promoting soil erosion via runoff and wind. Soil erosion deforms the soil structure and therefore creates an imbalance in soil fertility. According to Mehjin et al. (2019) [71] a bare land with poor soil structure and poor soil fertility cannot support the growth of plants on it. Ecologically this land cannot support other forms of life in it hence may lead to the collapse of the particular ecosystem. The influence of pesticides on soil microorganisms is dependent on physical, chemical and biochemical conditions, in addition to nature and concentration of the pesticides) [6,97].

Soil microorganisms are extremely important to enhance and/or maintain soil fertility and productivity which in turn has paramount influence on agricultural in general and crop production particularly. However, currently the beneficial soil microorganisms are highly affected due to increased pesticides usage in modern crop production system. Therefore, producers and policy makers should consider and focus on remedial actions to bring sustainable solution and enhance agricultural production and productivity.

### 2.2. Impacts on pollinators and species diversity

Pesticides usage can affect beneficiary organisms, including birds and other pollinators. Some natural pollinators, such as honeybees and butterflies, are very sensitive to pesticides. Pesticides can kill bees and are strongly implicated in pollinator decline, the loss of species that pollinate plants, including through

the mechanism of Colony Collapse Disorder (Hackenberg, 2007), in which worker bees from a beehive or Western honey bee colony abruptly disappear. Application of pesticides to crops that are in bloom can kill honeybees, which act as pollinators. According to Miller (2004) the USDA and USFWS estimate that US farmers lose at least $200 million a year from reduced crop pollination because pesticides applied to fields eliminate about a fifth of honeybee colonies in the US and harm an additional 15%. Since these are important pollinators of both crops and native plants, reduced number of natural pollinators can therefore result into reduced seed and fruit production which is both an ecological effect as well as economical effect (Khalil et al., 2011) [57].

Table 1. Some of the effect of pesticides on soil and soil microbes

| Effect | Sources |
|---|---|
| Altering its microbial diversity, biochemical reactions and enzymatic activity | Hussain et al., 2009; Munoz-Leoz et al., 2011 |
| Decreases the general biodiversity in the soil. | Mehjin et al. (2019) |
| Pesticides negatively affect microbial counts and activity in soil | Cycon et al., 2010; Mehjin et al., 2019 |
| Population of actinomycetes decreased by malathion treatment. | Walia et al., 2018; Haleem, et al., 2013 |
| Even if the pesticides used in low concentration they effect chemical and biological properties, biochemical activity and soil microorganisms. | Cycon et al., 2006; Singh et al., 2008; Cycon et al., 2010 |
| Affects soil enzymatic activity, cellular membrane composition, protein biosynthesis, and the amount of plant growth regulators (gibberellins synthesis, transportation of Indoleacetic Acid (IAA), ethylene concentration, etc.). The application of excessive and higher doses of herbicides has also been reported to result in the death of many sensitive microbes. | Milosevic et al., 2000 |
| Soil nematodes, earthworms and protozoa are affected by field application rates of the fungicide fenpropimorph and other herbicides. Application of fungicide, carbendazim resulted in reduction of various species of soil fungi extensively in first 20 days.<br>Affecting flora and fauna including microflora of soil, and also the physico-chemical properties of the soil like pH, salinity, alkalinity leading to infertility of soil. | Sarnaik et al., 2006; Aggarwal et al., 2005 |
| Disrupt the activities of soil microbes and affect the nutritional quality of soils. | Handa et al., 1999 |
| Increase or decrease in urease activity following various pesticide applications.<br>Inhibit dehydrogenase activity (DHA) in soil and decrease in total nitrogenase activity. | Ingram et al., 2005; Nowak et al., 2004; Mayanglambam et al., 2005; Singh and Wright, 1999 |
| Soils surrounding treated plants can become low in nitrogen compounds, so more fertilizer is needed to produce the same yield. | Fox et al., 2007 |
| Herbicide treatment significantly stimulated C and N mineralization in soil.<br>Both nitrogen mineralization and nitrification rates were influenced by fungicides. | Haney andSenseman, 2000; Chen et al., 2001; Martinez Toledo et al., 1998 |
| Fumigants used as nematicides and fungicides can profoundly influence mycorrhizal establishment.<br>Insecticides- chlorpyrifos has no effect on Mycorrhiza at low rate, but tends to suppress at high rate; whereas Phenylpyrazole inhibits Mycorrhiza | Sanjay and Divya, 2016; Ayman et al., 1996; Storer, 2012 |

Even though pollinators are extremely important in the pollination of crops and wild plants pesticides application is negatively affecting them which resulting in the considerably reduced yield of crops. Therefore, screening of pesticides for toxicity to bees and other pollinators, and the use of pesticides toxic to pollinators only under stringent conditions.

Likewise, pesticides being used in modern agricultural system are causing destruction of species diversity in their ecosystem. Beketov et al. (2013); Kennedy et al. (2013) and Hallman et al. (2014) [11,56,42] reported that, pesticide use

has particularly contributed to the declines in the populations of birds, insects, amphibians and aquatic communities. For instance, assessment conducted in Kenya shown that, the farmers identified declines in the number of pollinating insects, the disappearance of Red-billed Oxpecker (Buphagus erythrorthynchus) and wild bird's fatalities (Deborah et al., 2014) The effect is either direct through exposure, or indirect through a reduction in food availability. The widespread use of systemic pesticides that are absorbed by the crops is predicted to result in substantial impacts on biodiversity and ecosystem functioning (TFSP, 2015) [111]. Studies have shown that systemic insecticides from the group of neonicotinoids can trigger the collapse of bee colonies [14,36]. Moreover, widespread and continued herbicide application eliminates plant species in fields and bordering areas that provide food and shelter to beneficial insects, spiders and birds.

### 2.3. Impacts on fish and other aquatic organisms

Pesticides has potential side effect on aquatic organisms and/or fresh water ecosystems, such as fish, frog and others. According to Law (2014) [61] pesticides are now found in every habitat on earth and are routinely detected in both marine and terrestrial animals. Pesticides can enter surface waters via different routes, among which runoff driven by precipitation or irrigation is the most important in terms of peak concentrations. The exposure can cause direct effects on all levels of biological organization, while the toxicant mode of action largely determines which group of organisms (primary producers, microorganisms, invertebrates or fish) is affected [57,87]. Pesticides have been directly linked to causing fish mortality worldwide (Scholz et al., 2012). For example, 27 freshwater fish species are found to be affected by "plant protection products" (PPP) in Europe (Ibrahim et al., 2013) . Pesticides not only impact the fish but also food webs related to them. Many body tissues of the fish such as gills, alimentary canal, liver and brain of carp and catfish were found drastically damaged by pesticides. It was reported that such level of pesticides in fish could harm the fish consumers as well (Konar, 2011). Kelly et al. (2010) demonstrated that, exposure of trematode parasite (Telogaster opisthorchis), freshwater fish (Galaxias anomalus) and snails to high glyphosate concentrations significantly reduced their survival and development. The authors also reported that, within 24 hrs of exposure to higher glyphosate concentrations, 100% mortality of individuals was found. On the other hand, the impact of pesticides within an aquatic environment is influenced by their water solubility and uptake ability within an organism (Pereira et al., 2013) .

### 2.4. Impacts on water quality and air pollution

Water and air are easily and highly affected by pesticides. A large part of the pesticides applied to crops are either taken up by the plants and animals or are degraded by microbial or chemical pathways (Frank et al., 2015) [33]. Vorley and Keeney (1998) [119] reported that, a considerable fraction of the amount applied, however, is dispersed into the environment, by air drift, leaching and run-off so that they are found in soils, surface and ground water. Pesticides in freshwater supplies have become a serious and increasingly costly concern, with detected levels often exceeding the set limits (in the EU: 0.1 $\mu g^{-1}$ for any individual active ingredient or 0.5 $\mu g^{-1}$ for total pesticides). For example, in Switzerland, 70% of surface waters had pesticide levels above the official limit (Munz et al., 2012) [76]. When pesticides enter freshwater ecosystems, they do interact with the biotic and abiotic components of the ecosystem. Abiotic factors can lead to degradation (photo-decomposition by sunlight or hydrolysis by water) or adsorption of the compounds on sediment or organic matter. The interaction with the biotic parts comprises uptake, metabolisation and accumulation in organisms, which in turn may lead to adverse effects on the

freshwater biotic community (Ralf et al., 2011) [87].

Pesticide residues in water are a major concern as they pose a serious threat to biological communities including humans (Gill and Garg, 2014). Pesticides applied in the environment can find their way into water bodies either from the air or by runoff or by percolation to groundwater (Khalil et al., 2011) [57]. There are different ways by which pesticides can get into water such as accidental spillage, industrial effluent, surface run off and transport from pesticide treated soils, washing of spray equipment's after spray operation, drift into ponds, lakes, streams and river water, aerial spray to control water-inhibiting pests (Carter and Heather, 1995; Singh and Mandal, 2013). Pesticides generally move from fields to various water reservoirs by runoff or in drainage induced by rain or irrigation (Larson et al., 2010) . Pesticides leaching or draining from agricultural land may pollute surface and ground water (Deborah et al., 2014). Similarly, the presence of pesticides in air can be caused by number of factors including spray drift, volatilization from the treated surfaces, and aerial application of pesticides. Extent of drift depends on: droplet size and wind speed. Verro et al. (2009) reported that, pray drift is greatest when the spraying is conducted aerially using aircraft and for crops such as vineyards or orchards where the spraying occurs in a horizontal direction. The rate of volatilization is dependent on time after pesticide treatment, the surface on which the pesticide settles the ambient temperature, humidity and wind speed and the vapor pressure of the ingredients (Kips, 1985; Khalil et al., 2011) . The volatility or semi-volatility nature of the pesticide compounds similarly constitutes an important risk of atmospheric pollution of large cities (Trajkovska et al., 2009) . On the other hand, the quantitative relevance of the exposure route (airborne or waterborne) varies depending on physicochemical properties of the compound as well as the geographical, geological, hydrological and climatic conditions and crop type (Bach et al., 2001) [8].

### 2.5. Health effects of pesticides

The deleterious effects of pesticides on human health have started to grow due to their toxicity and persistence in environment and ability to enter into the food chain. Pesticides can enter the human body by direct contact with chemicals, through food especially fruits and vegetables, contaminated water or polluted air. Both acute and chronic diseases can result from pesticide exposure (Gill and Garg, 2014; Williamson, 2011; Richter, 2002) . Furthermore, it is now well noticed that most of the pesticides used in societies have been associated with toxicity to human and others are suspected to be causes of many diseases as summarized in Table 2 below. Annually there are dozens of million cases of pesticide poisonings worldwide (Richter, 2002) [93]. These health effects are different depending on the degree, and the type of exposure. Typically, the effects are different for farmers who are directly exposed to pesticides, compared to those for farmers' relatives or people living in rural areas who are less directly exposed. Farmers and pesticide applicators are particularly prone to adverse effects due to their direct exposure to pesticides at work. In addition, in agricultural areas where pesticides are heavily used the population nearby is also at risk. Pesticides drift in the air, pollute soil and water resources and can thus contaminate large areas. Moreover, acute pesticide poisoning is a serious problem in developing countries and emerging economies, where many farmers use highly hazardous products, often without adequate protective measures. The harms in actual conditions of use are experienced disproportionately by the poor and disadvantaged (IAASTD, 2009) [50]. Replacing highly hazardous pesticides such as endosulfan and paraquat with less toxic ones, and training farmers on proper handling of pesticides are expected to reduce acute poisoning (WHO, 2014) [125].

On the other hand, in the developed nations, the focus of concern has generally shifted to chronic effects due to low-level exposures (Pretty and Jules, 2005) [86]. Reffstrup et al. (2010) [90] suggested that the widest exposure to pesticides, however, is through residues in food. Exposure is presented as multiple mixtures of chemicals, the toxic effect of which are unknown, particularly over longer time scales. In some cases these substances can interact such that mixtures may have unpredictable and higher toxicities than the individual components themselves (Leu and André, 2014). Currently, the existence of pesticides residue in agricultural crops and their entrance into the trophic network has endangered human health and environment, and it has also necessitated the correct use of the pesticides (Khalil et al., 2011) [57]. Fruits and vegetables frequently have the highest levels of pesticide residues-food items that are generally eaten because they are deemed healthy. But also animal products contain pesticide residues that accumulate from feed or from treatment against parasites, or, in the case of fish and seafood, through bioaccumulation in the aquatic food web systems (Greenpeace, 2015) [37]. According to Forman et al. (2012) [31] people consuming an organic diet may be expected to have consistently lower pesticide intakes than those who consume a conventional diet. Likewise, some studies highlight that precautionary measures have a significant impact on the relationship between pesticides and disease (Sekiyama et al., 2007) [60], while others find significant interaction effects on health of pesticide exposure and genetic polymorphisms (Lacasaña et al., 2010) [60]. Generally, to reduce the health effects associated to agro-pesticides judicious usage and proper pesticide management is mandatory.

Table 2. Some of the effect of pesticides on human health and associated diseases

| **Health impact or diseases** | **Sources** |
|---|---|
| Hepatitis and dyspnea | Azmi et al., 2006 |
| Neuro degenerative diseases including Parkinson disease, Alzheimer disease | Elbaz et al., 2009; Hayden et al., 2010; Tanner et al., 2011 |
| Hearing loss | Crawford et al., 2008 |
| Myocardial infarction | Dayton et al., 2010 |
| Respiratory diseases (Asthma, Chronic obstructive pulmonary disease) | Hoppin et al., 2009 |
| Thyroid disease | Goldner et al., 2010 |
| Hormonal imbalances including infertility and breast pain | Xavier et al., 2004 |
| Affect sperm quality | Perry et al., 2011 |
| Chronic health effects, including cancer, neurological effects, diabetes, respiratory diseases, fetal diseases, and genetic disorders. | Gill and Garg, 2014; Williamson, 2011; Richter, 2002 |
| Cancer (Childhood and adult brain cancer; Renal cell cancer; lymphocytic leukemia (CLL); Prostate Cancer). | Heck et al., 2010; Xu et al., 2010; Band et al., 2011; Cocco et al., 2013 |
| Toxicity to human | Jacobs and Dinham, 2001 |
| Endocrine disruptors | Colborn et al., 2004 |
| Different pesticides have been implicated in chronic neurotoxicity, endocrine disruption, immune impacts, genotoxicity, mutagenicity and carcinogenesis. | Maroni and Fait, 1993; Abou-Donia, 2003; Galloway and Handy, 2003; Choi et al., 2004; Beard et al., 2011 |

### 2.6. Impacts on pest and pest management

Pest and their managements are influenced by pesticide usage or application. Currently, pest management is highly challenged by increasing pesticide consumption in modern agricultural system. According to Meyers and Bull (2002) and Cothran et al. (2013) , the increased quantity and frequency of pesticide applications have posed a major challenge to the targeted pests causing them to either disperse to new environment and/or adapt to the novel conditions. The adaptation of the pest to the new environment could be attributed to the several mechanisms such as gene mutation, change in population growth rates, and increase in number of generations etc. This has ultimately resulted in increased incidence of pest resurgence and appearance of pest species that are resistant to pesticides (Gill and Garg, 2014) . Pesticide use reduces populations of insects, spiders and birds that naturally control pests. Conventional use of insecticides can have deleterious effects on natural enemy populations because beneficial arthropods can have greater susceptibility to low concentrations of insecticides than their prey or host (Ruberson et al., 1998; Torres and Ruberson, 2004) [94,]. Pesticides exert a wide range of lethal (acute and chronic) and sublethal (often chronic) impacts on natural enemies (Rezaei et al., 2007; Ruberson et al., 1998; Stark et al., 2004). They kill natural enemies present in the field and ecosystem and destroy the natural equilibrium between the hosts and their natural enemies which in turn lead to pest populations increase rapidly and make more controlling efforts (Khalil et al., 2011; Paine et al., 2011; Rezaei et al., 2007). As pests usually recover faster than their predators, pesticide use can aggravate subsequent incidence of pest outbreak (Frank et al., 2015; Gill and Garg, 2014). In some cases reduced populations of beneficial insects due to overuse of pesticides contributed to the rise of pests that previously were of minor importance. Another growing concern is that pests and weeds increasingly develop resistance to pesticides. On the other hand, new pesticides are developed or combinations of pesticides are used in order to control them, resulting in additional costs and new side effects (Frank et al., 2015) [33]. Therefore, judicious usage of pesticide and appropriate pesticide management strategy are compulsory to reduce the side effects of pesticide on pest and their management.

## 3. Factors accelerating environmental effects of pesticides

The ecological effects of pesticides have been increasing from time to time due to many driving factors. Of this, increasing world population, repeated use of persistent and non-biodegradable pesticides, miss handling of obsolete pesticides, lack of technical and operational skill, and lack of proper pesticide management, weak linkage among stock holders and weak pesticide governance at various stages are the major factors. In general, knowledge of the driving factors is the key to lessen the risks. The increasing world population has therefore put a tremendous amount of pressure on the existing agricultural system so that food needs can be met from the same current resources like land, water etc. In the process of increasing crop production, herbicides, insecticides, fungicides, nematicides, fertilizers and soil amendments are now being used in higher quantities than in the past (Gill and Garg, 2014). Before introduction of synthetic pesticide, most weeds, pests, insects and diseases were controlled using sustainable practices such as cultural, mechanical, and physical control strategies.

The repeated use of persistent and non-biodegradable pesticides has polluted various components of water, air and soil ecosystem (Gill and Garg, 2014). Pesticides have also entered into the food chain and have bio accumulated in the higher tropic level. More recently, several human acute and chronic illnesses have been associated with pesticides exposure (Mostafalou and Abdollahi, 2012). The pesticides when used properly may pose low risk

to the environment and human health as long as strict controls are put in place (Deborah et al., 2014)· However, safe storage and disposal of pesticides and fertilizers remain a challenge in the agricultural areas. On the other hand, rapid expansion of the agriculture due to increasing population has resulted in increased demand for agro-chemicals in many counties, especially in developing nations and pesticides have become an integral part of plant, livestock and public health protection (NES, 2006). According to study conducted in Kenya, the general knowledge among farmers about chemicals risks, safety, and chronic illnesses was low (Deborah et al., 2014). Maroni et al. (2006) presented that the leading causes of work-related pesticide exposures are accidental spillage of pesticides, leakages from its packaging, not using or incorrect uses of equipment, and failure to comply with safety guidelines. People may be exposed to pesticides by producing, transporting, preparing for application, applying or entering pesticide-applied area (Damalas et al., 2011; Maroni et al., 2006; Stadlinger et al., 2013). Using pesticides-effected material or product is also a main source of exposition.

Obsolete pesticides are defined as stocked pesticides that can no longer be used for their original purpose or any other purpose and therefore require disposal (Deborah et al., 2014; Stadlinger et al., 2013) . However, environmental contamination and spillage are among the major problems caused by the use of expired pesticides. Point sources arising from stored obsolete pesticides have been identified as locally very important threats to the African environment (Elfvendahl et al., 2004; NES, 2006), while the consequences of diffuse use in agriculture has been less studied. Sereda et al., (2009) indicated that pyrethroids found in human breast milk may come from agricultural use. On the other hand, Bouwman and Kylin (2009) pointed out the need to include agricultural and other uses of pesticides when evaluating risks to infants from pesticides used for vector control. Donations of pesticides from developed countries have also caused environmental contamination in developing countries. This was partly due to the lack of information and available data on the amount present in the respective country. These donations have ultimately resulted in an accumulation of a stock of expired pesticides (Wandiga, 2001; Williamson, 2007). Generally, lack of proper pesticide management may result in health, environmental, and economic problems. Therefore, in order to lessen this negative impact, works should focus to design and implement the proper pesticides management strategies there by considering the key driving factors.

## 4. Pesticides risk reduction strategies

As well-known there are a lot of risks associated to pesticide usage which is increasing from time to time due to many factors. Hence, this is the time that necessitates the judicious use of pesticides to protect our environment and eventually health hazards associated with it. Besides, due attention is needed to mitigate the problems. Optimized use of pesticides is important to reduce environmental contamination while increasing their effectiveness against target pest. According to Rosell et al. (2008) ideally, the applied pesticides should only be toxic to the target organisms, should be biodegradable and eco-friendly to some extent. Unfortunately, this is rarely the case as most of the pesticides are non-specific and may kill the organisms that are harmless or useful to the ecosystem. In general, it has been estimated that only about 0.1% of the pesticides reach the target organisms and the remaining bulk contaminates the surrounding environment (Carriger et al., 2006). Moreover, Reus et al. (1999) [91] suggested that the environmental impact of pesticides depends on several factors such as pesticide active ingredient, dose rate, application frequency and method, environmental conditions (weather, soil type, geological formation), and site characteristics (available surface water resources, presence of biological species).

On the other hand, various strategies have been suggested to reduce the ecological impact of pesticides though only few of them have a reasonable chance of success under a variety of different circumstances. Of this, adoption of alternative pest control options like integrated pest management (IPM), appropriate agronomic practices, the use of resistant/tolerant varieties, bio control, the use of natural substances, safe application of minimal toxic synthetic pesticides as a last resort are key measures. Furthermore, consideration of important issues like lethal during screening of new pesticides, the use of biotechnology and nanotechnology, designing of new/easy pesticide formulation, building strong extension linkage among stockholders, design of ideal agricultural system, and strong policy development and implementation toward pesticide use are among the important approaches. Technical and operational aspects are the other main criteria for pesticide use. As highlighted by Xu et al. (2008) technical factors may constrain farmers to use alternative chemical pesticides. Knowledge and information about the appropriate use of pesticides is basic criteria that has been affecting their usage (Chen et al., 2013; Wange et al., 2017; Plianbangchang et al., 2009; Fan et al., 2015). Al-Zaidi et al. (2011) [4] suggested the need for the launching of extension programs on the proper and safe methods for pesticides handling and application. Likewise, authors demonstrated that, farmers should be enlightened about the importance of the frequent and regular medical checking up of their workers and especially those dealing with the agricultural chemicals. Deborah et al. (2014) indicated that activities which increase environmental awareness and safety of pesticides should be initiated by the agrochemical firms and governments. Smallholder farmers are mostly provided with too technical information on pesticides that are hazardous and involve a complex technology (Mengistie et al., 2017) [72]. Hence, sufficient technical information on the correct application of pesticides is required to be delivered to smallholder farmers by various experts through agricultural extension services. Zyoud et al. (2010) and Mohammad et al. (2018) [133] argued that farmers with good pesticide knowledge showed good practices in pesticide use and were more inclined to apply pesticides according to recommended guidelines for protective measures. Similarly, Chen et al. (2013) [16] revealed that the significant negative effect of pesticide overspray practiced by farmers can be reduced by improving their knowledge of pest management.

Alternative pest control strategies such as IPM that deploys a combination of different control measures such as cultural control, use of resistant genotype, physical and mechanical control, and rational use of pesticide could reduce the number and amount of pesticide applications (Gill and Garg, 2014). Further, advanced approaches such as biotechnology and nanotechnology could facilitate in developing resistant genotype or pesticides with fewer adverse effects. Community development and various extension programs that could educate and encourage farmers to adopt the innovative IPM strategies hold the key to reduce the deleterious impact of pesticides on our environment. Agricultural systems should be designed in a way that pests, diseases and weeds do not build up to a level that they cause significant damage to the crop. Suitable agronomic practices, the use of resistant varieties, and Integrated Pest Management are key preventive measures. Bio-control and the use of natural substances can complement these efforts. The safe application of minimal toxic synthetic pesticides should be used as a last resort (Frank et al., 2015) [33]. Some the common agronomic and other important pesticide risk management practices are explained in table-3 below. Manufacturers and researchers are designing new formulations of pesticides to meet the global demand (Gill and Garg, 2014). On the other hand, some important issues including natural enemy species, life stages/sexes, routes of pesticide entry, life

history parameters, plot size for field screenings and pesticide formulations and rates must be considered for designing bioassays evaluating the effects of pesticides on natural enemies (Ruberson et al., 1998; Vogt et al., 1992) [94,118].

Policies development and implementation is the important issue to reduce pesticide use and risks. International codes, treaties, conventions, commissions and advisory bodies play an important role in for plant protection and pesticide management. Through the ratification of international conventions, governments accept obligations to incorporate them into national policies (Frank et al., 2015) [33]. Moreover, the role of governments is to find a responsible balance between enabling judicious pesticide use where such use is necessary to achieve desirable crop production levels, and reducing the adverse health, environmental and agronomic risks (Pretty and Jules, 2005) [86]. Pesticide legislation and registration offers possibilities for regulating the availability and use of pesticides.

Table 3. The pesticide risk management strategies

| **Approaches** | **Practices** | **Mechanisms** | **Sources** |
|---|---|---|---|
| Agronomic practices | Appropriate plant nutrition and soil fertility management | It forms the basis for healthy crops that are less susceptible to pests. | FAO, 2011a; Gill and Garg, 2014; Rosell et al., 2008 |
| | Crop rotation | Prevents the carryover of pest, pathogen and weed populations to the following season. | |
| | Intercropping and the use of variety mixtures | Limits the spread of pests and diseases and provides food and shelter for natural enemies of pests. | |
| | Appropriate timing of sowing or planting and of intercultural operations | Reduce pest pressure. | |
| | Timely shallow tillage | Reduces weed populations and at the same time improves nutrient supply to the crop. | |
| | Appropriate irrigation management | Avoids water stress (too little or too much water) that makes crops susceptible to pests and diseases and reduces proliferation of weeds; | |
| | Precision farming | Spraying of hot-spots and weeding with optical detectors. | |
| Bio-control | Conservation and augmentation | Conservation and augmentation of natural enemies of pests through flower strips, hedge rows and other natural habitats. | FAO, 2011a; Frank et al., 2015; IAASTD, 2009 |
| | | Release of predators and parasitoids of pests such as Trichogramma, lady bird beetles, lacewings and predatory mites. | |
| | | Sprays with pathogens of pests such as *Bacillus thuringiensis*, *Beauvaria, Trichoderma* and nematode species. | |
| Pheromone and Traps | Pheromone | Pheromone dispensers to disrupt mating of pests. | FAO, 2011a |
| | Traps | Traps like sticky coloured boards, pheromone traps and light traps to catch insect pests. | |
| Natural pesticides | Plant extracts and other natural materials | Various plant extracts and other natural materials are used that repel pests, reduce their feeding or reproductive activities, reduce proliferation of diseases or act as bio-pesticides. | |
| Resistant crops | | The use of resistant varieties together with rotations of non-susceptible crops can substantially limit pest build-up within a field. | Pretty and Jules, 2005 |
| | | Genetic ability of the plant to improve its survival and reproduction by a range of adaptations as compared to the other cultivars when exposed to the same level of pest infestation. | Sharma and Ortiz, 2002 |

| | | | |
|---|---|---|---|
| Integrated Pest Management | Combine all compatible options and act to prevent pest | Act through integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. | FAO, 2015; Gill and Garg, 2014 |
| | | Strong focus is on pest prevention by applying good agronomic practices and using resistant varieties, pest identification and monitoring and biological pest control. | |
| Agro-ecology | | In agro-ecology pest control seeks to reinforce interactions of pests and natural enemies with the aim to maintain a natural balance in the ecosystem. | FAO, 2014; Khan et al., 2010 |
| Organic agriculture | Selection and application of suitable/eco-friend practices | Crop protection builds on good agronomic practices such as crop rotation and intercropping, the use of organic manures, resistant varieties and bio-control to prevent that pest, diseases and weeds cause significant damage. | Halberg and Müller, 2013; IFOAM, 2008 |
| Judicious use of pesticide | Timing of pesticide application | Appropriate application time can ensure not only maximum impact on the target organisms but also least impact on beneficial organisms. | Fishel and Ferrell, 2013; Dhaliwal et al., 2006 |
| | Dosage and persistence | Pesticide dose should be sufficient but no greater than the level required for best results. Persistent pesticides have their benefit of longer persistence on the target and therefore requires less frequent spraying compared to non- persistent pesticides. | Dent, 2000; Dhaliwal et al., 2006; Rosell et al., 2008 |
| | Selective placement | Distribution of pesticides in the field should be such that maximum target cover is achieved. | Dhaliwal et al., 2006 |
| Use of less hazardous pesticides | Phasing out the use of highly hazardous pesticides and replacing them with less hazardous ones | This is the most obvious way to reduce the negative side-effects of pesticides. This approach needs to be combined with safe handling of pesticides so that their impact on people and the environment is minimized. | FAO and WHO, 2015; Pretty and Jules, 2005 |

## 5. Conclusions

Pesticides play a great role to protect pest and increase productivity in agriculture. However, currently they are posing a lot of problems due to indiscriminate use. Most of the agrochemicals being used in modern agriculture negatively affect agricultural system and different environmental components. The prolonged intensive and indiscriminate use of agrochemicals adversely affected the soil biodiversity, pollinators and species diversity, fresh water community and/or aquatic organisms, water quality and air pollution, agricultural sustainability, food safety, human health, pest and pest management. Many factors can contribute in acceleration of environmental impact of pesticides which include increasing world population, repeated use of persistent and non-biodegradable pesticides, and lack of proper pesticide usage and/or management, weak linkage among stock holders and weak pesticide governance at various stages and others.

Currently, there is a need for proper use of pesticides to protect our environment and eventually health hazards associated with it. As clearly highlighted in this review, there are a lot of strategies that have been suggested to reduce pesticide use and associated risk in agricultural system. Implementation of alternative pest control strategies such as integrated pest management, biocontrol, the use of botanical extracts, and rational use of pesticide that could reduce the number and amount of pesticide applications play a great role. Appropriate agronomic practices and other organic farming methods offer promising options are need to be strengthened and promoted. Further, advanced approaches such as biotechnology and nanotechnology are needed to facilitate the development of resistant genotype in breeding or pesticides with fewer adverse effects.

Moreover, agro-ecology, integrated pest management and the use of alternatives need to be integrated in vocational education, training and technical advice to farmers. Likewise, as farmers mainly learn from practical experience it is crucial to demonstrate alternatives in plot trials and pilot farms and to facilitate the exchange of know-how. In addition it is important that farmers are made aware of the risks associated with pesticide use and get equipped with feasible measures to reduce these risks.

On the other hand, pesticide reduction is a shared responsibility of the overall society, including scientists, farmers, consumers, governments and the private sector. Thus, more public research is needed in order to advance the design of better farming systems and the development of alternatives to synthetic pesticides. Pesticides manufacturers should conduct long-term studies on ecosystem-wide impacts to demonstrate that a pesticide has no adverse effects before allowing it to be registered for use in the environment. Furthermore, governments need to adapt or introduce regulations and policies that ensure the pesticide risks are minimized, that pesticide use is reduced and that alternative systems and methods are endorsed.

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