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Sustainable Management of Pesticides

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Abstract: Pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest (insects, mites, nematodes, weeds, rats, etc.), including insecticide, herbicide, fungicide etc. used to control pests and to safeguard public health. Use of pesticide has secured the food production and enhanced the amount of produce. Once the pesticide enters in contact with the environment, its fate is determined by several natural processes (adsorption, degradation, erosion and leaching to groundwater). Of the total pesticides applied in agriculture, about 1-10% reach to the target plant, about 30% is lost in atmosphere, nearly 1-5% is lost due to runoff/surface erosion and roughly 1% is lost by leaching. Pesticides applied in the soil leaches up to 50 -100 %. Pesticide management reduces contamination of water from pesticides and foster effective and safe use of pesticides without causing degradation to the environment. This study provides an overview of pesticides on recent developments in sustainable management on strategies, practices and their effectiveness, core elements, principles of Integrated Pest Management (IPM) and bio-pesticides in crop protection. This study recommends that during application of pesticides, guidelines approved by FAO and WHO (2014), from production to disposal of pesticides in the 'International Code of Conduct on Pesticide Management' (4th version) should be strictly followed by government regulators, the private sector, civil society as a best practice in managing pesticides throughout their lifecycle.

Keywords: Bio-pesticides, Crop protection, Integrated Pest Management, Pesticides, Pests, Sustainable management

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Introduction

Use of pesticide has changed considerably over the past five decades. This was influenced by pest pressures, environmental and weather conditions, crop acreages, agricultural practices, access to land-grant extension personnel, crop consultants, cost-effectiveness of pesticides, protection of crop

yields and quality, technological innovations in pest management systems/practices, and environmental and health regulations (Fernandez-Cornejo *et al*., 2014).

Agriculture has most important contribution in Indian economy and around 70% of the total population is employed under agriculture sector. Pesticides and fertilizers are the integral part of modern agriculture and pesticides such as insecticides, fungicides and herbicides were used to manage the weeds and pests (Nayak and Solanki, 2021). Pesticides are mainly used for benefits like crops protection, preservation of food materials and prevention of vector borne diseases. They are used in agriculture, forestry, aquaculture, food industry, processing, transportation and storage of wood and other biological products (Pillay, 2017).

Hassaan and Nemr (2020) reported that about 2 million metric tons of active ingredients of pesticides are in practice. These 2 million tons of pesticides can be divided into 47.5% herbicides, 29.5% insecticides, 17.5% fungicides and 5.5% other pesticides. Pesticides have become an integral part of modern life and are used to protect agricultural land, stored grain, flower gardens and to eradicate the pests transmitting dangerous infectious diseases (Gill and Garg, 2014).

Application of plant protection measures such as chemical pesticides minimized the heavy losses accruing due to insect-pests, diseases, rodents, weeds etc. (Cooper and Dobson, 2007). Persistent rise in crop yield and thereby improved farm income also tends to increase the expenditure on the use of chemical pesticides. However, in the recent times there is growing concern of the health hazards associated with pesticide usage. Environmental contamination from the use of pesticide ranges from water, air and soil pollution to alteration of the ecosystem resulting in detrimental effects to non-target organisms (Singh *et al*., 2006).

Fernandez-Cornejo *et al*. (2014) described that indiscriminate use of pesticides by the farmers to prevent or manage pest infestations have generated economic benefits for farmers and consumers but public concerns about the adverse effects on the environment and human health leads to tighten the regulation of these products. In recent times, use of pesticides has changed considerably with respect to the total quantity, active ingredients and small annual fluctuations in the annual pesticide use.

According to Ghosh *et al*. (2015), the credit of increased production of food and fibre, and amelioration of vector-borne diseases goes to pesticides, their indiscriminate use have resulted in serious health implications to human and to the environment. The general concept of "if little is good, a lot more will be better" has violated the basic concept of need based application of pesticide and become one of the important factor of environmental contamination.

The U. S. Department of Agriculture (USDA) and Environmental Protection Agency (EPA) have promoted Integrated Pest Management (IPM) practices to develop new methods to manage pests and to create awareness among farmers for the methods of use of pesticides. IPM mainly focus on innovative approaches of pest management by new seed varieties, crop rotation, pest and weather information and predictive models to use pesticides. Pest management issue becomes the need of the hour due to the development of issues such as glyphosate-resistant weed populations, herbicide-tolerant corn, cotton, and soybeans and development of Bt resistance in western corn rootworm, cotton bollworm, and fall armyworm (Fernandez-Cornejo *et al*., 2014).

Kafilzadeh *et al*. (2012) documented that of the total quantity of pesticides applied in the agriculture, only 1-10% reach plant target part and from the remaining, nearly 30% is lost in atmosphere (volatilization or drift/dust), about 1-5% is lost due to runoff/surface erosion and roughly 1% is lost by leaching, which can generate undesirable amount of pesticide residue. Roughly 50% of the pesticides applied in the agriculture, enter the soil and underwent adsorption,

Table 1: Selected definitions of pesticides

Reference	Definition of Pesticide
Nicolopoulou-Stamati *et al*. (2016)	Substances or mixtures of substances that are mainly used in agriculture or in public health protection programs in order to protect plants from pests, weeds or diseases, and humans from vector-borne diseases, such as malaria, dengue fever, and schistosomiasis.
Bauder *et al*. (2020)	Any substance or mixture of substances used to directly control pests or to prevent or reduce the damage they cause.
Assad *et al*.(2021)	Any substance or concoction of substances premeditated for preventing,repelling, eradicating, killing or mitigating any pest (weeds, insects, pathogens, bacteria, fungi, viruses, nematodes, snails, mites, and/or rodents) menacing animal/human health and agricultural/industrial production.

degradation, erosion and leaching to groundwater. Hence, it is a need of the hour to adopt innovative strategies for pest management and to minimize the quantity of pesticide residues in the environmental components (Ghosh *et al*., 2015).

Pesticide management is practised to reduce contamination of ground and surface water from pesticides. It foster effective and safe use of pesticides without causing degradation to the environment. Pesticides should be applied within the context of sustainable agriculture. The legislation frameworks and implementation of IPM principles plays a key role in the sustainable use of pesticides (Lykogianni *et al*., 2021). The IPM include using natural or ecologically sound principles or techniques to prevent the pest from reaching the economically damaging levels, and using multiple tactics, including cultural, biological, and chemical control (Singh *et al*., 2006).

Despite many peer reviewed scientific studies, and the consolidated knowledge about the adverse impacts of pesticides at the global level, there are still gaps in knowledge and information that need to be addressed (UNEP, 2022). To overcome the knowledge gaps and further research on innovative ideas on environment friendly and less toxic pesticides, present study was undertaken. This study provides an overview of pesticides, exclusively on recent developments in sustainable management on strategies, practices and their effectiveness, core elements, principles of Integrated Pest Management (IPM) and bio-pesticides in crop protection.

Definition of Pesticides:

Table 1 illustrates the definition of various pesticides which has been given by other researchers.

This article reviews the pesticides with respect to definition and strategies for sustainable management. Review method adopted was based on the scientific literature survey from databases such as Scopus, Medline, EMBASE, Web of Science and Science Direct. The relevant data and information were collected from the thorough study of the journal articles, research papers, reports and various literatures. The keywords used for reviewing the literature were the ones that refer to the issues concerning the pesticides. For literature search, keyword "pesticides" is combined with: definition; agronomic practices; selection and application; Government agencies and scientific intervention; control by cultural, physical and mechanical, biological and chemical agents; Integrated Pest Management and bio-pesticides.

Sustainable Management of Pesticides (*Fernandez-Cornejo et al., 2014*):

Management strategies for pesticides (*Ghosh et al., 2015, EU, 2017*):

The strategies for management of agricultural

pesticides should be planned by consideration that once the pesticides entered into the environment, their behaviour cannot be controlled. Emphasis should be given on innovative and environment friendly management strategies for the protection of human health and the environment. Due to varying agroclimatic conditions and soil physicochemical properties, fate of same pesticide becomes unpredictable. Hence, management strategies should be adopted to reduce pesticide load in environment (Ghosh et al., 2015).

Suitable management strategies, acceptable and applicable by the farming community, hold the key of safe and sustainable environment. Management strategies include agronomic practices, pesticide selection and application and Government agencies and scientific intervention (Singh *et al*., 2003).

Cooper and Dobson (2007) described that few traditional pesticide management strategies were used by famers which could significantly reduce pesticide related risks, however, these methods are unable to control the problem of pest resurgence. Few of these methods include:

- Alteration of pesticides with different modes of action.
- Avoiding unnecessary persistence.
- Bio-pesticides.
- Monitoring of pest population in field before any pesticide application.
- Natural predators: Lady beetles, mantises, spiders, and parasitic wasps.
- Restricting number of applications over time and space.
- Targeting pesticide applications against vulnerable stages of pest life cycle.
- Trapping methods.
- Use of pheromones: Disturb the natural mating cycles of the pests.
- Using synergists (enhance the toxicity of pesticides by inhibiting the detoxification mechanisms).

❖ *Agronomic practices*:

- Avoid application of pesticides adjacent to surface water.
- Clean cultivation to minimize pest infestation.
- Conservation of tillage decreases chances of runoff loss.
- Consultation with competent authority for selection of suitable pesticide.
- Crop rotation should be practiced to control pest outbreak.
- Integrated pest management (IPM) system should be practiced.
- Introduction of natural predators for controlling insects.
- Pest/disease tolerant or resistant varieties should be preferred.
- Practice of trap crops and crops with allelopathic effects.
- Reduce steepness of slope, heavier soils, and conventional tillage.
- Regular monitoring of pest population up to economic threshold level (ETL).
- Testing of physicochemical properties of soil to reduce leaching of pesticides.
- Use of biopesticides and biological control.

❖ *Pesticide selection and application:*

- Application of pesticide during no chances of rain or heavy wind.
- Careful dispose of pesticide containers after application.
- Harvesting after suitable waiting to minimize pesticide load in final produce.
- Mixing or alternating pesticides: Mixtures of pesticides with different mode of action to reduce chances of development of resistance.

- Preparation of solution/mixture of pesticides on a loading floor to avoid contamination due to spillage.
- Selection of registered pesticides for a particular crop.
- Selection of pesticides: Low dose, less toxicity, target specificity, leachability and fast degradation, no/low residue on produce.
- Suitable formulation of pesticides to minimize loss.
- Use of suitable equipment for pesticide application.

❖ *Government agencies and scientific intervention*:

- Identification and marking: Misbranded, sub-slandered and spurious pesticides marked.
- Public awareness: Banned, restricted, misbranded, sub-slandered and spurious pesticides.
- Regular monitoring: Pesticide products to ensure label claim.

❖ *Cultural control* (*Russell labs, 2015*):

- Make crop environment less suitable for insect pests.
- Use as a preventative measure for pests.
- Most effective for target insect pests.
- Adopted throughout the world.
- Environmentally friendly and require minimal costs.
- Types: Crop rotation, sanitation, soil solarization, timed planting and harvest, use of resistant varieties, certified seeds, allelopathy, intercropping or companion planting, use of farmyard manure, and living and organic mulches.

❖ *Physical and Mechanical Control* (*Cooper and Dobson, 2007*):

➢ *Physical control*:

- Control pests by removing, attacking, or setting up barriers.
- Use primarily for crop growing.
- Remove or kill pests, or keep pests away from hosts by a barrier or trap.
- Little impact on natural enemies and other non-target organisms.
- Manages pest populations using devices.
- Types: Exposure to sun rays, steaming, moisture management (for stored grain), and light traps (for attracting moths, beetles and other pests).

➢ *Mechanical control*:

- Suppression of pest population by manual devices.
- Practices: Hand picking, trapping and suction devices, clipping, pruning and crushing of infested shoots and floral parts, and exclusion by screens and barriers to keep away house flies, mosquitoes and other pests.

❖ *Biological Control* (*Dhaliwal et al., 2006*):

- Uses natural enemies of particular pests to reduce their populations.
- Bio-control agents: Parasitoids, predators and pathogens.
- Techniques: Introduction, conservation and augmentation of natural enemies.
- Bio-control agents: Vertebrates, nematehelminthes (flatworms and roundworms), arthropods (spiders, mites and insects), pathogens (viruses, bacteria, protozoa, fungi, rickettsiae).

❖ *Chemical Control* (*Fishel, 2011*):

- Preventive and curative method to minimize the insect pest damage.
- Spray droplet size, density of chemical dosage and application timing plays major role.

- Directions on the pesticide label should be followed to prevent injury to non-target organisms.

Pesticide Management Practices and Their Effectiveness:

The pesticide management measure identifies a series of steps that producers should use in managing pesticides. Good soil and water management are also essential for effective pesticide management. To reduce contamination of ground and surface water from pesticides, six general principles guide should be practiced for safe pesticide management (Singh *et al*., 2006; FAO, 2012; WHO, 2012; FAO and WHO, 2014).

Inventory current and historical pest problems, cropping patterns, and use of pesticides for each field:

This is helpful to farmers in evaluating the potential for water contamination at the site and to determine IPM strategies which may be applied to the operation. It requires map of farm and field and following information for each field:

- Crops to be grown and a history of crop production.
- Information on soil types.
- Exact acreage of each field.
- Records on past pest problems, pesticide use and other information for each field.

Evaluate the soil and physical characteristics of the site (*mixing, loading and storage areas for potential for the leaching/runoff of pesticides*):

The most important types of features for evaluation include:

- Sinkholes, drainage wells, abandoned wells, and karst topography which allow direct access to ground water.
- Proximity to surface water.
- Runoff potential (steeper slopes, heavier soils, and conventional tillage).
- Aerial drift.
- Soils with a high risk of erosion.
- Soils with poor adsorptive capacity.
- Highly permeable soils..
- Shallow aquifers.
- Wellhead protection areas.

Use IPM strategies to minimize the amount of pesticides applied:

This includes:

- Scouting fields for pest problems.
- Determine the economic threshold for pests.
- Use varieties of crops resistant to pests.
- Use crop rotation.
- Foster biological controls.
- Use of improved tillage practices such as ridge tillage.
- Use of cover crops to promote water use and reduce percolation of water.
- Destruction of pest breeding, refuge, and overwintering sites.
- Mechanical destruction of weed seed through the use of tillage techniques.
- Diversification of habitat.
- Use of trap crops.
- Use of allelopathic characteristics of crops.
- Use of timing of field operations (planting, cultivating, irrigation and harvesting).
- Use of efficient application methods (spot spraying and banding of pesticides).

Screening of pesticide based on persistence, toxicity, and runoff and leaching potential and also current label requirements for selection:

- Apply pesticides as per instructions on the label of each pesticide product.
- User must be trained and certified for proper use of the pesticide.

- Labels: Allowable use rates; classification of pesticides as “restricted use” for application only by certified applicators; safe handling, storage, and disposal requirements.
- Grower practices and movement of pesticides into surface water: Tillage practices, incorporation, and filter strips reduce pesticide movement to surface water.

Maintain records of application of restricted use pesticides:

Records of application of restricted use pesticides should be maintained for 2-years after use, as per the requirements of Farm Bill.

- Product name.
- Amount utilized.
- Date of application.
- Location of application of each such pesticide used.

Use only recommended amount of pesticide and determined to merit pesticide application (Oyler Jr, 2000).

Recalibrate and repair application equipment, including chemigation equipment, at least each spray season:

- Use of anti-backflow devices on hoses used for filling tank mixtures and on chemigation systems.
- Calibration of pesticide spray equipment at least once each spray season.
- Calibrating equipment saves money and reduces damage to the environment.
- Purchase new, more precise application equipment and other related farm equipment.

Solid pad for mixing and loading pesticides:

- Solid pad for mixing and loading.
- Practice new technologies for reducing mixing and loading risks.

Core elements of Sustainable Pest Management:

OECD (2022) putforth the 'Vision for the future' for sustainable pest management (SPM) should include following core elements:

- Harmonisation of the regulatory systems and work sharing to help improve the registration system.
- Sustainable approach towards plant protection.
- Reduction of risks arising from agricultural pesticides.
- Enhanced communication on regulatory processes and decisions.
- Partnering with non-OECD countries

The Principles of Integrated Pest Management:

The European Parliament (2021) is actively promoting the use of the eight principles of IPM formulated for 'sustainable pesticide use directive'.

The eight principles of IPM include:

- Prevention;
- Monitoring;
- Decision-making based on thresholds;
- The use of non-chemical pest control measures;
- The selection of the most specific pesticides;
- The use of the lowest necessary dosages of pesticides;
- The use of anti-resistance strategies;
- The evaluation of the measures’ success.

Bio-pesticides in Crop Protection (*USEPA, 2008; EU, 2017*):

- Introduced to lower the hazardous impacts of the chemical pesticides.
- Reliable and efficient source of controlling the pests.
- Include micro-organisms or extracts from such organisms or plants which only inflict the damage or harm-causing pests.
- Do not have adverse and side effects on the

plant body and the environment.

- Best possible substitutes of the chemically originated pesticides.
- Highly efficient, target-specific and do not tend to impose any annihilating or deteriorating impact on the environment.
- Groups based on the active ingredient present: Microbial bio-pesticides and botanical bio-pesticides.

Microbial Bio-pesticides (*Meena et al., 2020*):

- Include pathogens: Fungi, bacteria, and viruses.
- Formerly known as 'biocontrol' agents.
- Most efficient and causing no toxicity in the environment.
- About 3000 species of biocontrol agents.
- Pathogenic micro-organisms are used as active ingredient of the microbial pesticides against species other than their hosts. .
- May be used in combination with chemical pesticides.
- Narrow specificity and are used with conventional synthetic pesticides.
- Examples:

✓ Bio-fungicides: *Trichoderma*, *Pseudomonas*.

✓ Bioherbicides: *Phytophthora* spp.

✓ Bio-insecticides: *Bacillus thuringiensis*, *Pseudomonas* spp., etc.

Botanical Bio-pesticides (Stevenson et al., 2012):

- Obtained from any plant part or the whole plant body.
- Neutralize or kill the harmful pests and/or control of the weeds.
- New and innovative agriculture practices.
- Traditional agriculture practices including organic farming.
- Over 6000 species of plants have the insect-killing potential (insecticide).
- Environment-friendly, with lubricious property and little surrounding prospects.
- Low residual activity and affect less number of non-target species of insects.
- Show compatibility with integrated pest management (IPM) programs.
- Can lead to pest resistance if used in improper and excessive quantities.
- Phytotoxicity is a matter of concern with some botanical bio-pesticides.

✓ Examples: Neem (*Azadirachta indica*), Tobacco (*Nicotiana tabacum*), Pyrethrum etc.

Conclusion

Use of pesticides is an integral component to enhance the agriculture produce and to prevent vector-borne diseases. Indiscriminate and overuse of pesticides have resulted into contamination of environment and harmful effects on human health. As pesticides are an important group of chemicals, they need to be carefully managed. To improve the productivity, sustainability and livelihoods of farmers everywhere, effective implementation of guidelines of 'International Code of Conduct on Pesticide Management' should be followed. Promotion of the eight principles of IPM formulated for 'sustainable pesticide use directive' by The European Parliament (2021) also safeguard the health of environment and human.

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