Chapter 1
Conventional Methods of Pesticide Application in Agricultural Field and Fate of the Pesticides in the Environment and Human Health

V. Dhananjayan, S. Jayakumar and B. Ravichandran

Abstract The increasing growth of world population required raising overall food production. In order to meet the requirement, food supply factors of increasing yields, expanding agricultural area and increasing the productivity of crop and animal agricultural are necessary. As a consequence, application of pesticide for protection of crop involves wide variety of chemicals with various applicable techniques. The pesticides are very commonly used in agriculture sector with several methods of applications in recent years. However, in developing countries, the conventional method of application of pesticide is the major practice. The knowledge and awareness of application play a major role in fate of pesticides in the environment and human health. Several studies have reported the handling practices and subsequent exposure of farmers to pesticides and pesticide accumulation. In addition to the preparation and application of pesticides, there are several important problems related to pesticide use that should be understood by every applicator. Generally, in the conventional way, application of pesticides did not include any regular inspections for safety procedure and follow-up inspections of problem areas. Some of the methods, however, may result in problems such as over application, not reaching the pest habitat while using a minimum amount of pesticide, and depositing unsafe residues. Proper techniques of application not only aid in effectiveness but also ensure workers' safety, public protection and protection of the environment. Although newer pesticides are capable of degrading fast, the adverse impact of these chemicals with already existing persistent pesticides on environment including humans is reported in recent years. The application of pesticide is not merely the operation of sprayer or duster. It has to be coupled with a thorough knowledge of the pest problem. The application techniques ideally should

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be target oriented so that safety to the non-targets and the environment is ensured. Therefore, environmentally responsive controlled release of pesticide through advance technologies is needed and recommended. This chapter deals with the different types of pesticide application, their distribution and occurrence in the environment and human health-related issues.

Keywords Pesticide application · Fate of pesticides · Health effects

1.1 Introduction

Agriculture is the most important enterprise and it is the major key to economic development in many developed countries. The agriculture remains traditional and labour intensive; little or no external inputs are used. Pest management practice under these conditions is a built-in process in the overall crop production system rather than a separate well-defined activity [1]. The most important concern associated with agricultural production is the problem of pests (weeds and insects). An important step for raising productivity and increasing the gross output of agricultural products is the elimination of losses of the harvest due to pests, plant diseases and weeds. The farmers use pesticides to control weeds, microbes, insects, rodents and other higher organisms to protect their crops and preserve food materials [2–4]. In the initial stages of agricultural practice, the cultivation together with crop and animal husbandry was largely eco-friendly, although the yields were not as high as of the present day. During 1874, the German chemist Othmar Zeidler had first synthesized dichlorodiphenyltrichloroethane (DDT) compound, but failed to realize its value as an insecticide. Similarly, a series of chemical pesticides were synthesized to protect crop plants against insect pests. While the immediate benefits of these pesticides were indeed quite impressive, their long-term harmful effects on environment and non-target organisms came to be understood only after much damage to ecosystems had already been done. After the description of Carson [5] on deleterious effects of DDT and other chlorinated pesticides in her book on 'Silent Spring', there has been a growing campaign against the use of chemical pesticides in agriculture. As an alternative to the organochlorine pesticides (OCPs), organophosphates (OPs) and carbamate pesticides are largely used in agriculture field. The introduction of these synthetic insecticides—organophosphate (OP) in the 1960s, carbamates in 1970s and pyrethroids in 1980s—and herbicides and fungicides in the 1970s–1980s contributed greatly to pest control and agricultural output. Ideally, a pesticide must be lethal to the targeted pests, but not to non-target species, including man. Unfortunately, this is not the case, so the controversy of use and abuse of pesticides has surfaced. The rampant use of these chemicals, under the adage, "if little is good, a lot more will be better" has played havoc with humans and other life forms.

During the past three decades or so, a significant amount of Integrated Pest Management (IPM) or IPM-related research has been conducted in many parts of the world including in the developing countries [4, 6]. However, the use of chemical pesticides continue for a long time in small quantities, particularly in highly populated developing countries like India and China [7]. Agriculture in the twenty-first century faces multiple challenges: it has to produce more food and fibre to feed a growing population with a smaller rural labour forces and more feedstocks for a potentially huge bio-energy market, contribute to overall development in many agriculture-dependent developing countries, adopt more efficient and sustainable production methods and adapt to climate changes [8]. There is limited scope for significantly expanding agricultural land after constraints and trade-offs are considered. The incorporation of new lands into production is likely to come with important social and ecological constraints and costs. Therefore, the initiation of exploitative agriculture without a proper understanding of the various consequences of every change introduced into traditional agriculture, and without first building up a proper scientific and training base to sustain, it may only lead us, in the long run, into an era of agricultural disaster rather than one of agricultural prosperity.

The conventional methods of pesticide applications are the major practice in developing countries. Persistence and accumulation nature of pesticides on various stages of food chain and environment affects human. Humans are exposed to pesticides through occupational or environmental exposure. The occupational exposures occur among rural workers, greenhouse workers, workers in pesticide manufacturing [2]. The group that receive the greatest exposure are those who involved in mixing, loading, transporting and applying pesticides. Furthermore, the lack of training and equipment to safely handle pesticides increases the health risk [9]. Gangemi et al. [10] summarized the most recent findings on the association between occupational pesticide exposure and the development of chronic diseases. As regards to environmental exposure, this mainly affects the general population through the consumption of polluted food and drinking contaminated water or using pesticides in the home or living close to sprayed fields. Thus, risk assessment and prevention from pesticide exposure are not a simple process, particularly when we consider several limitations, such as differences in the time and the levels of exposure, the class of pesticides (chemical structure and toxicity), mixtures or cocktails used, and the geographical and climate features of the areas where pesticides are applied. For these reasons, it has been suggested that pesticide safety should be tested before and after marketing, in order to evaluate whether the estimated or predicted individual exposure on a given task is suitable [11].

Pesticide applicators utilize many methods in the application of pesticides. Most of these methods have been developed as the result of years of studying the most effective methods. Some of the methods, however, may result in problems such as over application, not reaching the pest habitat while using a minimum amount of pesticide, and depositing unsafe residues. Proper techniques of application not only aid in effectiveness but also ensure workers' safety, public protection and protection of the environment [2–4, 12]. Competence in pest control includes basic knowledge of pests and pest problems, the ability to choose the right pesticides and equipments, and knowledge of proper methods of application. The proper technique of application probably plays a greater part in achieving the target job. Therefore, the present chapter was aimed at exploring the existing conventional method of pesticide application and the consequence of pesticide in man and environment. A brief continuation of the types of equipment and techniques of application used in agriculture practices, maintenance of equipment, knowledge of pesticide applicator, fate of pesticides in the environment, health of effects associated with pesticides and various modern techniques in controlled release of pesticides in agriculture field are presented in the following section.

1.2 Importance of Pesticide Application

Agriculture was developed to produce crops and livestock for human consumption. As the human population increases, the amount of food produced is very important. Unfortunately, there are other organisms out there that want to consume the crops that are meant for humans. It is estimated that nearly 37% of all crops produced in the USA each year are destroyed by agricultural pests, which results in an economic loss of around $122 billion a year. Due to this high loss in food production, pesticides are often used to combat the problem. There are many different types of pesticides on the market today, but the most common are herbicides and insecticides, which kill or manage unwanted plants and insects. The damage caused by agricultural pests is a global problem, and over the past half-century, the amount of pesticides used have increased severalfold. Over the years, the widespread use of pesticides had several benefits and also have caused damage to the environment and human health [12–15]. The benefits of pesticides include increased food production, increased profits for farmers and the prevention of diseases. Although pests consume or harm a large portion of agricultural crops, without the use of pesticides, it is likely that they would consume a higher percentage. Due to the use of pesticides, it is possible to combat pests and produce larger quantities of food. By producing more crops, farmers are also able to increase profits by having more produce to sell. Pesticides also increase farm profits by helping the farmer save money on labour costs. Usage of pesticides reduces the amount of time required to manually remove weeds and pests from fields. In addition to saving crops and livestock, pesticides also have direct benefits to human health. It is estimated that since 1945, the use of pesticides has prevented the deaths of around seven million people by killing pests that carry or transmit diseases. Malaria is transmitted by infected mosquitoes, known as deadly diseases to human that have decreased in prevalence due to the use of pesticides. Other diseases were also minimized due to the use of pesticides include the bubonic plague transmitted by both fleas and body lice [13]. Similary several diseases are being curtailed by application of pesticides.

1.2.1 Benefits of Pesticides

The primary benefits are the consequences of the pesticides' effects—the direct gains expected from their use. For example, the effect of killing caterpillars feeding on the crop brings the primary benefit of higher yields and better quality. The main effects result in primary benefits ranging from protection of recreational turf to saved human lives. The secondary benefits are the less immediate or less obvious benefits that result from the primary benefits. They may be subtle, less intuitively obvious or of longer term. It follows that for secondary benefits it is therefore more difficult to establish cause and effect, but nevertheless they can be powerful justifications for pesticide use. For example, the higher cabbage yield might bring additional revenue that could be put towards children's education or medical care, leading to a healthier, better educated population. There are various secondary benefits identified, ranging from fitter people to conserved biodiversity.

1.2.2 Improving Productivity

Tremendous benefits have been derived from the use of pesticides in forestry, public health and the domestic sphere—and, of course, in agriculture, a sector upon which the countries like Indian economy is largely dependent. Food grain production stood at a mere 50 million tons in 1948–49, had increased almost fourfold to 198 million tons by the end of 1996–97 from an estimated 169 million hectares of permanently cropped land. This result has been achieved by the use of high-yield varieties of seeds, advanced irrigation technologies and agricultural chemicals (Employment Information: Indian Labour Statistics, 1994). Similarly, outputs and productivity have increased dramatically in most countries, for example wheat yields in the UK and corn yields in the USA. Increases in productivity have been due to several factors including use of fertilizers, better varieties and use of machineries. These pesticide are used to control various pests and diseaes carriers, such as mosquitoes, ticks, rats and mice [16]. Therefore, pesticides have been an integral part of the process by reducing losses from the weeds, diseases and insect pests that can markedly reduce the amount of harvestable produce. There are many different types of pesticides; each is meant to be effective against specific pests. Some examples are given in Table 1.1.

Table 1.1 Type of pesticides used and its target function

S. no.	Pesticide	Target species/function
1	Acaricide	Mites, ticks
2	Algaecide	Algae
3	Anticoagulant	Rodents
4	Attractant	Attracts insects or birds
5	Avicide	Birds
6	Bactericide	Bacteria
7	Defoliant	Plant leaves
8	Desiccant	Disrupts water balance in arthropods
9	Fungicide	Fungi
10	Growth regulator	Regulates insect and plant growth
11	Herbicide	Weeds
12	Insecticide	Insects
13	Miticide	Mites
14	Molluscicide	Snails, slugs
15	Nematicide	Nematodes
16	Piscicide	Fish
17	Predacide	Vertebrate predators
18	Repellent	Repels vertebrates or arthropods
19	Rodenticide	Rodents
20	Silvicide	Woody vegetation

1.3 Types of Application

Pesticide application plays an important role in pest management. Proper technique of application of pesticide and the equipment used for applying pesticide are vital to the success of pest control operations. The application of pesticide is not merely the operation of sprayer or duster. It has to be coupled with a thorough knowledge of the pest problem [2, 4, 17]. The use of pesticides involves not only of knowledge on application equipment, but also of pest management as well. The main purpose of pesticide application technique is to cover the target with maximum efficiency and minimum efforts to keep the pest under control as well as minimum contamination of non-targets. All pesticides are poisonous substances, and they can cause harm to all living things. Therefore, their use must be very judicious. The application techniques ideally should be target oriented so that safety to the non-targets and the environment is ensured. Therefore, proper selection of application equipment, knowledge of pest behaviour and proper dispersal methods are vital [15, 17–19]. The complete knowledge of pest problem is important to define the target, i.e. location of the pest (on foliage, under the leaves, at root zone, etc.). The most susceptible stage of the pest for control measures will help to decide the time of application. The requirement of coverage and spray droplet size depends upon the mobility and size of the pest. The mode of action of pesticide, its relative toxicity and other physicochemical properties help to decide the handling precautions, agitation requirement, etc. Further, the complete knowledge of the equipment is necessary to develop desired skill of operation, to select and, to estimate the number and type of equipment needed to treat the crop in minimum time and to optimize use of the equipment.

The objective of the application of pesticide is to keep the pest under check. The pest population has to be kept suppressed to minimum biological activities to avoid economic loss of crop yields. Thorough killing of pest or eradication of pest is neither practical nor necessary. The objective of pesticide application besides keeping the pest population under check should also be to avoid pollution and damage to the non-targets. The success of pest control operations by pesticide application greatly depends on the following factors:

1. Quality of pesticide.
2. Timing of application.
3. Quality of application and coverage.

Different types of pesticides are used for controlling various pests. For example, insecticides are applied against insect pests, fungicides against crop diseases, herbicides against weeds, etc., in order to protect the crop losses. But it is essential that besides choosing an appropriate pesticide for application it has to be a quality product, i.e. proper quantity of pesticide active ingredient (*a.i*) must ensure that the quantity is maintained in production and marketing of pesticide formulations. The application of pesticide is very successful when applied at the most susceptible stage of the pest. If the timing of pesticide application is carefully considered and followed, the results will be good and economy. Therefore, for large area treatment, careful selection of equipment becomes necessary so that within the available time the area could be treated. Even though good quality pesticide is used, an optimum timing for the application of pesticide is also adopted; unless the pesticide is applied properly, it will not yield good results. Therefore, the quality of application of pesticides is very important in pest control operations. The following points can be ensured during pest control operation.

1. Proper dosage should be applied evenly.
2. The toxicant should reach the target.
3. Proper droplet size.
4. Proper density of droplet on the target.

The dosage recommendation is generally indicated for acre or hectare, e.g. kg/ha or L/ha or g *ai*/ha. It should be properly understood, and the exact quantities of the formulated pesticide should be applied.

Pesticides are dispersed by different methods like spraying, dusting, etc. For spraying of pesticides, different types of nozzles such as hydraulic, air blast, centrifugal and heat energy type are used. Water is a common carrier of pesticides, but air or oils or soap solutions are also used as carriers. Selection of proper droplet is an important consideration. The shape, size and surface of the target vary greatly. For spraying against flying insects, the hydraulic nozzles will not be effective. Hence fine size spray particles are needed to remain airborne for longer time. However, for weed control operation, usually the requirement is drift-free application or coarse spray droplets. An adequate number of spray droplets should be deposited necessarily. For fungicide application, the number of droplets deposited per unit area should be more, and maybe for translocated herbicide application, it can be less in number. It may need fewer numbers of droplets to be deposited in case of highly mobile (crawling) insect pests. The pesticides are formulated in liquid form, dust powder or granule forms such that it makes possible to apply small quantities of pesticides over large area. Some of the pesticides are applied as low as few grams *a.i.* per hectare. Therefore, the adoption of proper application technique is vital for uniform depositing of pesticide.

1.4 Equipments Used for Applications

1.4.1 Spraying Techniques

The liquid formulations of pesticide are either diluted (with water, oil) or directly applied in small drops to the crop by different types of sprayers [20]. Usually, the formulations and wettable powder are diluted suitably with water which is a common carrier of pesticides. In some cases, however, oil is used as diluent or carrier of pesticides. The important factors for spray volume consideration are depends upon the spray type and coverage, total target area, size of spray droplet and number of spray droplets. It is obvious that if the spray droplets are in coarse size, then the spray volume required will be larger than the small size spray droplets. Also if the thorough coverage (e.g. both the sides of leaves) is necessary, then the spray volume requirement has to be more.

On the basis of the volume of spray mix, the technique of spraying is classified as:

1. High-volume spraying (300–500 L/ha).
2. Low-volume spraying (50–150 L/ha).
3. Ultra-low-volume spraying (<5 L/ha).

The range of volume of spray mix in each of the above case is arbitrary. Usually, for field crop spraying, the spray volume ranges are taken as guide. There is distinct advantage in the case of lower volume application over the high-volume application. The higher the volume to be applied, the more the time, the more the labour and the more the cost of application due to labour cost. However, the lower volume applications are concentrated spraying of pesticide which should also be considered properly.

1.4.2 Dusters

Dust formulations are pesticides in which the active ingredient is mixed with a substance which is usually light in weight (talc or clay). However, heavier weighted carriers are also essential for the proper distribution in certain situations. Many lightweight dusts are not acceptable in many areas since they may be a hazard to the applicator or vicinity in which the application is made [17, 21, 22]. Ultimate drift of dispersed dust must be of considerable concern to the applicator. Precautionary measures in the use of dust equipment consist of the following:

- Because dusts are usually exerted under some degrees of pressure, all working parts of the equipment should be carefully examined.
- All literature provided by the manufacturer should be carefully read.
- Goggles and respirators should be included in the safety equipment.
- The operator should be acquainted with operations and limitations of each piece of equipment.
- Complete removal of dust remaining in the hopper and any extensions of the duster should be accomplished after the completion of job.

1.4.2.1 Hand-Operated Dusters

Getz Applicator A simple device in which a spring is surrounded by a rubber sleeve sealed at one end by a filler plug and the other by a small release tube. Contracting the two ends compresses the spring and releases a limited quantity of dust through the tube orifice. Releasing the grip on the spring forces the sleeve to resume its original position. The capacity of this device is very small (six ounces), and usually, it is only used for crack and crevice treatment. It is one of the most versatile equipment used for all field crops. Small void areas can be expertly treated with this device [17].

Flexible Bulb This is similar to the Getz applicator but does not depend upon a spring to re-establish its flexibility. Instead, by the nature of its construction, it resumes its original shape and upon compressing releases dust through a small orifice. Depending upon the weight of the dust used, it may hold slightly more than the Getz applicator. Its uses are identical as for the Getz applicator. It is highly applicable for any powdered insecticides and being used effectively in home gardens [17].

Plunger Tube Dusters It is simple in construction and consists of a dust chamber, a cylinder with a piston or plunger, a rod and a handle. Retraction of the plunger allows air and dust to mix in the cylinder and upon depression of the cylinder, repeats the above process. This device is suitable for crack, crevice or void applications. Its capacity is usually greater than both of the previously mentioned dusters. It is highly useful for small-scale use in kitchen garden and in household (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Hand Crank Dusters These dusters have a hopper for the dust which varies in capacity from 1 to 10 lb. At the bottom of the hopper is an orifice which is adjustable in size and which allows the dust to fall into an airstream created by fins attached to a shaft. The shaft in turn is attached to a crank which is driven by hand power. A tube of varying length leads from the hopper to the final area of dispersion. This unit is typically used exteriorly or occasionally under the sub-areas of a house (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Foot Pump Dusters This is really a duplicate of the plunger-type duster, but in the place of the fixed release tube a hose is substituted and a place to set the operator's foot is provided. The plunger propels the dust through the tube, usually into a rodent burrow. In most cases, this style of duster is used in exterior areas (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Power Dusters As their name implies, the following equipment either uses electric motors, gasoline engines or compressed air as the power to run the mechanism which propels the dust. Where the hand-type units are usually for small applications, power dusters are obviously used where large quantities of dust are to be dispersed. In the structural pest control industry, this type of duster is usually restricted for use in large enclosed areas such as attics or sub-areas. However, where necessary and practical, exterior application is in order. Drift hazard and time of application are definite limiting factors in their use (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Electric Motor-powered Dusters This equipment, as indicated by the name, uses an electric motor which powers the propeller that creates the air to force the dust through an applicator tube. The hoppers for these dusters usually hold from 5 to 15 lb. One of the distinct limiting factors is the necessity for the availability of electricity which, in some instances, could limit the application area [17].

Gasoline Motor-powered Dusters The most common example of this is the knapsack or backpack duster. However, there are also wheel-mounted units for large-scale applications. In this type of duster, gasoline-operated engines accomplish the same effect as outlined above for the electric motor. Particularly, with the knapsack or backpack, there is an extremely large area of mobility because the power unit is self-sustaining. Also, many of these units can be used with minor changes for both dust and liquid applications. The hopper in the case of a dust applicator has a capacity of 5–25 lb [17].

Air Pressure Dusters This type of duster is a modification of the fire extinguisher so as to enable the air pressure built up within the tank to expel dust through a hose. Its limitations are that the quantity of dust is small (1–2 lb) and additional equipment must accompany the unit to build up air pressure. A truck-mounted air compressor or gasoline facilities could also be used. Once the unit has been filled with dust and pressured with air, it is self-sustained until either the dust or the air is dissipated. Except for the above limitations, it is a very flexible piece of equipment for the treatment of cracks, voids, sub-areas and attics (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Bellows Duster It has a pair of bellows made of leather, rubber or plastic. The bellows can work with a handle just like a Blacksmith does. The dust is placed either in the bellows or in a separate container made of wood, metal or plastic attached to one end of the bellows. The air current that is created runs through the container and drives the dust out through an opening.

Hand Rotary Duster They are also called crank dusters and fan-type dusters. They may be shoulder mounted, back or belly mounted. Basically, a rotary duster consists of a blower complete with gearbox and a hopper with a capacity of about 4–5 kg of dust. The duster is operated by rotating a crank, and the motion is transmitted through the gear to the blower. The air current produced by the blower draws the dust from the hopper and discharges out through the delivery tube which may have one or two nozzles. It is used for dusting field crops, vegetables and small trees and bushes in orchards. The efficiency of these dusters is 1–1.5 ha/day (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

1.4.3 Sprayers

There are many ways to classify equipment in this category. The present system is based on the method by which the pressure is originated to force the liquid from any designated holding container [20–22].

1.4.3.1 Hand-Operated Sprayers

Flit Gun This is probably one of the oldest types of sprayers used in the industry. Its basic principle of operation is that a plunger is situated above a small supply container. As the plunger is compressed, air is diverted through a small hole situated above a syphon tube from the supply container. When the air passes through the tube and siphons, the pesticide liquid from the tank reaches the nozzle tip. Because of tremendous advancements in equipment, this type of sprayer is seldom used today in pest control operation.

Small Hydraulic Sprayer This sprayer is the adaptation of the equipment that used in service stations to spray oil in a pin stream to springs and other lubricated parts of an automobile. It consists of a small supply container, rarely exceeding a quart. Inserted into this container is a tube enclosed plunger which is connected to a hand-pulled trigger. By exerting pressure on the trigger, the plunger forces liquid through a tube to an adjustable nozzle. The nozzle can be adjusted from a pinpoint sprayer to cone shape. Either oil base or stable emulsions can be used in this equipment. More often than not, this sprayer is used to apply a residual insecticide rather than a knock-down formulation. One distinct disadvantage is the small capacity of this applicator. This type of application has few uses for spraying the yard and sub-area (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Compressed Air Sprayers This is probably the most commonly used sprayer in our industry. It is composed of a tank (usually holding from one-half to 3 gal of liquid), a pump to compress air and a discharge hose with a valve to control the discharge through a nozzle. An airtight tank, preferably stainless steel, is filled approximately to three-fourths of its capacity with a pesticide, and its operation is relatively simple. The remaining space is utilized for the compressed air to be generated by the hand-powered plunger-type cylinder within the tank. A check valve is located at the bottom of the cylinder to allow the air to enter the tank but closes to prevent the liquid from entering the cylinder. A tube within the tank is located so that its source originates near the bottom of the tank but closes to prevent the liquid from entering the cylinder. Somewhere prior to the nozzle is a hand-controlled shut-off valve. There is usually a pressure valve where the pipe emerges from the tank and the hose connection. The sprayer should not be used with pressure exceeding 50 psi nor less than 25 psi. The nozzle can be either a multi-purpose type (pin stream to fan or hollow cone) or a fixed pattern. This type of application is usually confined to inside work and sometimes outside in monthly service calls. Most likely the greatest use of this type of application is in cockroach clean-out calls (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

1.4.3.2 Electric or Gasoline-Operated Sprayers

Powered Spraying For the most part, power spray usually refers to the typical 50–100 gal spray rigs owned by most structural pest control firms. Most will have some form of agitation, either jet agitation or blades mounted inside the tank. When spraying either a yard or sub-area, a moderately low pressure with a relatively high volume will aid in a safe even distribution. Where grass or weeds are thick, it may be necessary to adjust the pressure upwards to be sure and drive the pesticide down into the soil or turf. However, the spray pattern should be kept coarse to ensure wetness. Low pressure, high volume is particularly valuable when spraying a dry, dusty sub-area. High pressure tends to ball up the top layer of dust or soft soil and move it around in a sweeping motion, without ever getting the soaking action that is desirable. Needless to say, some servicemen will use higher pressure to speed up a job. A conscientious applicator will move about with a low-pressure, high-volume type of application and reach all areas. This power can be transmitted to the pump by belts and pulleys, chains and sprockets, power take-off assemblies or direct drive. In all cases, the liquid is ejected by the action of a pump through hoses or wands and finally through a nozzle or groups of nozzles. In this industry, the most commonly used type of pumps is the centrifugal, gear and piston pumps. The selection of a sprayer must obviously be governed by the magnitude of the job. Various types of formulations also play an important part in deciding the tank, pump, hose, regulator or nozzle to be used. The following section indicates the various ramifications of this selection by pointing out the various components of some of the systems now in use (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Tanks They should be of a capacity commensurate with the job. This seems, in most cases, to be of the 50–100 gal capacity. There are tanks available as large as 500 gal. The tank should be of stainless steel, aluminium, fibreglass, plastic or steel which is coated interiorly with a protective lining or is galvanized. The filling opening should be large, equipped with a strainer and be of a size large enough to enable easy access for repair of the lining or any mechanical device within the tank. A secure hatch should cover the filling opening to avoid spillage of the formulation while in use. In order for the tank to be adaptable to all types of formulations, it should have a mechanical agitator or a properly placed return of the overflow from the regulator. A drain should be located at the lowest point of the tank and, preferably, should be easily accessible. The inlet to the pump should be of adequate capacity to supply the needs of the pump. An exterior plastic or glass liquid level gauge should be available to check the actual or remaining quantity of pesticide in the tank. All of the newer tanks and liners have been developed to overcome the serious problem of corrosion.

Pumps A pump is the most important part of the spraying system. It is imperative that it is chosen to satisfy the widest range of applications unless its use is for a single purpose. In most instances, the pump comes as an integral part of a complete unit in which the engineering requirements have been satisfied. In other words, it has been specifically designed and manufactured by a company in this field. As one can imagine, there are many styles of pumps, some specifically for high gallonage delivery with little pressure, while others are styled for both small and large delivered quantities and high pressure. The most common types of pumps are discussed in the following section.

1. **Piston Pump**: It is one of the most common pumps in existence, which has the ability to produce large volumes at high pressure—for example, 55 gal per minute at 800 psi. However, it can also be regulated to deliver 2 gal per minute at 150 psi. The only feature which makes this type of pump undesirable is its pulsating action on hoses and regulators which causes them to wear at a rate faster than that with other types of pumps.
2. **Centrifugal Pumps**: It is one among the best pumps noted for its ability to deliver high volumes of liquid at low pressure. These are constructed to handle corrosive and abrasive materials.
3. **Roller Pumps**: This is a popular pump in the industry because of its wide variety of uses. It has either nylon or rubber rollers and can produce a wide range of volumes and pressures.
4. **Internal and External Gear Pumps**: These are the high-pressure pumps which produce limited volumes. Although all pumps diminish in efficiency from wear, this is more critical in this specific model.
5. **Diaphragm Pump**: It is one of the low-volume pumps and the main restriction is related to using a material which will not affect the material of the diaphragm.
6. **Flexible Impeder Pump**: It is a pump restricted to low pressure and limited volume.
7. **Vane Pump**: This pump requires materials which afford some lubricating properties.

Hoses The object of any hose is to convey a liquid from the power source to the target. The material of which hoses are made varies considerably. Originally, most hoses were constructed of natural rubber, but today, synthetic rubber, plastic or sometimes both are commonly used. As with so many other aspects of equipment in this industry, it is important to know what is expected of the hose relative to performance.

Nozzles There are many types of nozzles, of which the primary concern is that the specific type provides the pattern desired. Generally, the pattern is confined to a solid/pin stream, to a fan or to a hollow/solid cone nozzle. Many of the above combinations are available in adjustable brass, but can also be made of stainless steel, aluminium and sometimes wearable parts of plastic. Except for nozzles used on small equipment, the gallonage delivered by a specific nozzle, regardless of design, should be clearly known by the applicator. The capacity of the pump, the pressure on the liquid, the friction loss and size of the hose, and the size of the orifice in the nozzle will govern the ultimate gallonage delivered from the nozzle.

Strainers These are screens made of various materials, preferably stainless steel, which usually are 50 mesh or coarser. They are located at the filling opening, suction line to the pump and the nozzle tip. Their presence is to prevent any foreign substance access to the spraying system. Routine cleanings are imperative not only for the sprayers to function properly, but also extremely important if the calibrated delivery system is functioning accurately.

Valves There are many types of valves with some being extremely sophisticated. Their purpose is to shut off the flow of the liquid. Consequently, they are strategically located to be most effective in the advent of an emergency or in the normal function of the shutting off of the supply of liquid pesticides.

Pressure Regulators As the name implies, this unit controls the pressure of the liquid being delivered to the nozzle. As with many other parts, there are numerous types of regulators. Spring tension which is controlled by a hand-adjusted screw mechanism exerts pressure on the liquid as it flows through the regulator on its way to the nozzle. They can be operated from zero pressure to as high as 800 psi. The indicator/gauge for pressure is located adjacent to or is a component part of the regulator and, as indicated, records the pressure as pounds per square inch. In addition to establishing the pressure, a provision exists for the excess or overflow to bypass the regulator and return to the tank. In many sprayers, this return line is located near the bottom of the tank and can be either the primary or secondary measure in the agitation of the spray material in the tank.

Agitators This is a means by which the contents of a spray tank are mixed and agitated. The object is to keep the pesticide in continuous suspension so that it results in an even distribution of the material. In some formulations (wettable powders), mechanical is the only type of agitation that maintains suspension. In this method, a set of paddles is attached to a horizontally located shaft at the lower portion of the tank. Exteriorly, the shaft is connected to the power source. Bypass agitators are a frequently used method of agitation. This technique utilizes the overflow from the regulator to stir the contents of a tank.

Gas Generating Sprayers There are essentially two types of gas generated sprayers, floating piston type and the very common aerosol spray-cans. In the former, a cylinder with a floating piston having nitrogen gas is in one end of the cylinder and the pesticide, which is pumped under pressure of 300–1000 lb/in.^{2}, at the opposite end. This compresses the piston against the nitrogen and forces the insecticide through a high-pressure hose into a very fine orifice nozzle. Although it can be used independently for a limited time, it depends upon a pump situated reasonably close to the job for reloading. Aerosol can dispersal of pesticides, although not new, has been very popular both with the public and with pest control operators. Their range in capacity, from 6 oz to 30 gal, has made them very popular. The small sizes have push type release nozzles, while those with a capacity of 5 lb and up have a mechanical shut-off nozzle. They also come particularly in the sizes of less than 5 lb, in disposable type containers. Their construction is very simple, consisting of a container in which designated amounts of pesticides and freon are placed. As long as the temperature in the vicinity of the area, the material to be dispersed, is warm, the freon will propel the pesticide out of the orifice.

Farmworker applying liquid insecticide using hand-operated backpack sprayer (photo by S. Jayakumar)

Farmworker applying liquid insecticide using power-operated sprayer (photo by S. Jayakumar)

Farmworker applying liquid insecticide using backpack sprayer with round nozzle (photo by S. Jayakumar)

Farmer applying granular pesticide without using personal protective equipment (PPE) (photo by S. Jayakumar)

Granular Application As the name implies, the applicator used to apply granular formulations of pesticides in field. Essentially, these are small hopper-type units with an orifice for the material to drop onto the crank-operated spinning disc which throws the material over a 15- to 20-foot swath. Also, the same equipment is available in gasoline or power take-off drives which employ the same above principle only on a larger scale. Granules are ready for immediate application. Granular applicators, except in the case of weed control, are rarely used in pest control process (TNAU Aagritech Portal, http://agritech.tnau.ac.in/index.html).

Brush Application Brush application quite often is recommended on the label for use in areas where a wet application is desired; however, care is to be exercised in preventing the movement of a pesticide to non-target areas. This technique is usually confined to application along baseboards, window sills and door thresholds.

Fumigant Injection The only fumigant injection method which might be used by a structural pesticide applicator, other than those described in the section on fumigation, is local spot injection for control of dry wood termites and wood boring beetles. This technique utilizes a small hand-held CO_2 pressurized application with a nozzle designed to penetrate into either the small emergence holes created by the insects or specially drilled holes which open into the galleries.

Spot Treatment Spot treatment is an application to limited areas on which insects are likely to occur, but which will not be in contact with food or utensils and will not ordinarily be in contact with workers. These areas may occur on floors, walls and bases or outsides of equipment. For this purpose, a ‘spot’ shall not exceed two square feet.

Crack and Crevice Treatment Crack and crevice treatment is the application of small amounts of insecticides into cracks and crevices in which insects hide or through which they may enter into a building. Such small openings commonly occur in expansion joints, between different elements of construction, and between equipment and floors. These openings may lead to voids such as hollow walls, equipment legs and bases, conduits, motor housings or switch boxes.

Ultra-Low-Volume Application (ULV) Ultra-low-volume application is the spraying of undiluted pesticides in small volume, usually at rates of 1/2 gal per acre or even less. This term when used in structural applications has a somewhat different meaning. It is sometimes referred to as ultra-low dosage (ULD). The principle of ULV application is the dispensing of a low volume of insecticides over relatively larger areas. This technique is accomplished by breaking the insecticides down into tiny particles prior to applications.

Soil Injection This technique employs a long hollow, pointed probe connected to a spray rig and a shut-off valve at the top of the injector. It is mostly used in placing termiticides deep into the soil around exterior foundation.

Sub-Slab Injection This technique is used for treating soil beneath slabs for the control of subterranean termites. It is one of the most useful tools developed for termite control. The sub-slab injector can be adapted to both 1/2 and 3/4-in holes drilled in slab. The inability to know exactly the direction of the flow beneath the slab is considered as the disadvantage of this technique. The application method depends on the nature and habits of the target pests, characteristics of the target sites and properties of the pesticide formulations. One must consider the suitability of the application equipment, cost and efficiency of alternative methods.

Wiper Applicator It could be used to wipe a non-selective herbicide to selectively kill individual weeds. The wiper’s wetness must be less than dripping and handled carefully to avoid accidentally treating desired plants.

1.5 Maintenance of Equipment

Plant protection machines in general are not well maintained regularly either in godowns/depots where they are stored or in the field where they are used. Life of a machine depends entirely on its care and maintenance. Even though machines are made with high standards of skill and workmanship, they can easily be ruined due to improper care and maintenance. Good and constant performance from machines can be obtained only when they are used and serviced periodically. The purpose of maintaining a machine is for increasing the useful life of the machine and to be available in working order whenever put to use. The maintenance of a machine involves proper care, operation, servicing, repair and keeping it in good working order.

1.5.1 Maintenance

Normal maintenance jobs include cleaning the equipments and applying necessary lubricating oils and greases to the rubbing and moving parts. If this normal maintenance is neglected, the machine gets rusted and moving parts wear out quickly resulting in loss of efficiency, frequent replacement of spare parts and finally uneconomical working. Besides the normal maintenance as above, special care has to be taken for maintaining the plant protection equipments. The pesticide formulations are chemically aggressive on metals/other materials. The cleaning and washing of the chemical tanks, discharge lines, nozzles, etc., are to be done regularly after the day's spraying work is completed; otherwise the residues of chemicals used for spraying act on the parts and cause corrosion and deterioration of materials. If this aspect of thorough cleaning is not done on the plant protection machine, even though it is made of high standard materials, it will not serve its normal life and would lead to premature condemnation.

1.5.2 Maintenance of Hand-Operated Equipments

1. Cleaning the chemical tanks, hoses, valves and nozzles, etc., and flushing sufficiently to avoid pesticide residue which is corrosive.
2. Cleaning the machine equally well from outside also as it is contaminated due to leakage and spilling of pesticides.
3. Lubricating suitably the pump parts like piston, cylinder, valves and other rotating, sliding, moving parts.
4. Storage of machine in dry place duly protected from sun and rain.

1.5.3 Maintenance of Power-Operated Equipments

All the above maintenance jobs apply to power equipments also. But the engines have to be taken care of specially. All engines need fuel, air and proper system of ignition. Thus, in petrol engine, clean petrol, clean air and healthy ignition (spark plug and magnets) are essential. Besides those, the engine also needs perfect lubrication. In two-stroke petrol engine, care must be taken to mix lubricating oil and petrol in exact ratio as recommended by engine manufacturer. Similarly, in four-stroke petrol engine, the lubricating oil should be kept in sufficient quantity by observing the level gauge. The air cleaner should be cleaned occasionally. The spark plugs should be also cleaned, carbon removed and proper electrode gap should be maintained. The two-stroke petrol engines used in low-volume spraying should invariably be in good order; otherwise, the pesticide spraying will not be efficient. Sufficient care should be taken at the depots to clean, oil and check equipment periodically when they are stored, whenever machines are sent out to work, and when returned from fieldwork. This minimum care to inspect the equipment, clean and flush and keep it duly oiled, would go a long way in improving the availability of good working sprayers and dusters and also prolonging their useful life [21].

1.5.4 Repairs and Replacements

The plant protection equipment is often found requiring frequent repairs and replacements in nature. Hand-operated equipment generally needs minor repairs such as replacement of plunger washers, springs and nozzle, and these repairs could as well be attended by the operators themselves with little training and experience. It is essential to supply them the necessary spare parts and tools well in time for repairing. In the case of power-operated sprayers, the engine repairs are classified into minor and major respires.

1. **Minor Repairs**: Spark plug cleaning and adjustment, air cleaner, carburettor cleaning, fuel cock and lines cleaning and starter repairs are considered as minor retirements; it can be attended by the operators themselves with little experience and training.
2. **Major Repairs**: These repairs include replacement of parts like piston, rings, liners, crankshaft, bearings, valves, etc. These repairs have to be carried out systematically in well-equipped workshops by the competent and trained mechanics. Untrained personnel should not be allowed to handle such major repairs.

1.5.5 Suggestions on Maintenance

To improve the maintenance of sprayers and dusters, the following suggestions are made:

1. Plant protection equipment manufacturers, their dealers, state agricultural engineering workshops and extension officers need better coordination and cooperation to reduce the number of sick equipment.

2. The field operating staff needs to be given the orientation training on proper maintenance, repairs, operations and calibration of equipment on periodic basis.
3. An adequate number of mechanics and supervisory staffs have to be posted for checking the maintenance and effectiveness of equipment.
4. A district-wise service station could be established, which certainly facilitates the users to repair their power-operated equipment within their zone.

1.5.6 Safety Systems

Pesticide Containment Pad If one often stores, handles, mixes and loads pesticides, or cleans equipment at the same location, one must have to install a pesticide containment pad (as per EPA to determine when a containment pad is required). These pads are designed to contain spills, leaks, overflows and wastewater for reuse by the applicator or for disposal by a commercial waste management contractor. They make it easier to clean up spills and help to prevent environmental contamination.

Impervious Containment Pad Generally, the containment pad must be made of impermeable material. It should be concave or have curbs and berms/walls high enough to hold the largest amount of spill, leak or equipment wash water likely to occur at the site. It must also have a system to remove and recover spilled, leaked or released material by either an automatic pump system or a manually operated pump. Smaller, portable pads and lightweight trays made of heavy-duty plastic may be used when mixing and loading at the application site.

1.5.7 Sprayer Components

Tank A tank is necessary to contain the spray mix. Choose one made of, or coated with, a material that does not corrode and that can be cleaned easily. Cleaning prevents accumulations of corrosion and dirt that clog screens and nozzles, increasing wear on the equipment. Large tanks require an opening in the bottom to aid in cleaning and draining. A large top opening is useful for filling, cleaning and inspecting the tank. The opening must have a watertight cover to prevent spills. A tank agitation system/device is useful for most sprayable formulations, especially for wettable powders or dry flowables. Constant mixing of a pesticide and liquid carrier produces a uniform spray mixture (suspension) and results in an even application of the chemical.

Exposure to sunlight and corrosive chemicals can shorten the life of polyethylene tanks.

Three common signs of wear and potential tank failure are as follows:

- **Scratches** are on the surface could be noted.
- **Crazing** is a network of fine lines/cracks that may look like a patchwork, but often cannot be seen with a visual inspection. Crazing can be seen when using one of the testing methods explained below. Crazing occurs within the tank wall and can be a sign of deterioration of the plastic, which may lead to cracks. Tanks that show signs of crazing will still hold liquids, but the integrity of the tank is questionable. For this reason, caution should be used when putting any hazardous substance in tanks that show crazing.
- **Cracks** extend through the plastic wall and can be visually seen and felt. Cracks may run parallel or at right angles to each other.

Pump A pump agitates the spray mixture and produces a steady flow to the nozzles. Pump parts must resist corrosion and abrasion, especially when wettable powders or similar formulations are used. Pump will never be operated at speeds or pressures above those recommended by the manufacturer. Pumps depend on the spray liquid for lubrication and to prevent overheating.

Nozzle Maintenance In general, the correct screen size for each nozzle could be selected. Cleaning of nozzle tips could be carefully done with a soft brush, but not wire or a knife tip, which may damage the nozzles.

Sprayer Cleanup Spray equipment should be cleaned in the field after the spray job has been completed. Some pesticide labels provide specific information on cleaning spray equipment, and one should consult the label for guidelines. The users do not clean spray equipment in areas where rinse water will contaminate water supplies, streams or injure susceptible plants, wildlife and human.

Flushing spray equipment with water may be sufficient to remove potentially harmful amounts of many pesticides. However, certain groups of pesticides may require special attention. Thorough clean-out procedures are critically important when switching applications between crops to help avoid significant crop injury. As a rule, a sprayer that has been used to apply 2,4-D or other growth regulator-type herbicides should not be used to treat susceptible plants. A triple rinse—water, then ammonia, then water again—minimizes the risk of injury from dicamba and 2,4-D. Inconsistent applications result in control failures or injury to turf or landscape plants. Things to watch for when using this type of application are as follows:

- Pump pressure is set correctly.
- Consistent, accurate walking speed.
- Nozzle is correct for desired flow rate.
- No partially blocked nozzle openings.
- Hose is not kinked.
- Strainer screen is not clogged.

1.6 Knowledge of Pesticide Applicator

Pesticide usage in agricultural practices has become a crucial part of present-day farming and takes part in a foremost role in increasing the productivity of agricultural product. However, the indiscriminate and widespread use of pesticides stands for one of the major environmental and public health problems across the world [23, 24]. Pesticides are very important 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. The improper usage of pesticides is a significant sources of air, water and soil contamination, which can lead to destruction of non-target species [25, 26]. The most persistent and toxic nature of pesticide residues in agricultural products jeopardizes both the environment and human health. In global scale, it was estimated that approximately 200,000–300,000 people die every year due to the pesticide exposure [27, 28]. It has also been estimated that only about 0.1% of pesticides used reach the target organisms, and all other remaining portions of pesticides applied were entered into the surrounding environment.

At a global scale, a large number of casual and temporary workers are engaged in agriculture sector. Unpaid family members carry out agricultural work as unrecognized farm labour or support small-scale family farming. In recent years, there has been an increase in the use of pesticides in developing countries, and they now account for about 20% of the world's expenditure on pesticides [29]. Researchers have concluded that farmworkers in developing countries will continue to use pesticides in increasing quantities because of the lack of alternatives to pesticides and ignorance of the sustainability of pesticide use. Extensive use of such pesticides results in substantial health and environmental threat. Despite the instructions provided on pesticide containers, there are several hurdles that restrict their implementation. Lack of education among farmers and farmworker is the foremost barrier.

A recent review by Dhananjayan and Ravichandran [30] highlighted the detrimental health effects of farmworkers associated with pesticide exposures. Farmers involved in the handling of pesticides are at a high risk of exposure to pesticides through contact with pesticide residues on treated crops, unsafe handling, storage and disposal practices, poor maintenance of spraying equipment, and the lack of protective equipment or failure to use it properly [31]. Studies in developing countries reported low to moderate levels of knowledge about pesticides among farmworkers [32, 33].

Sodavy et al. [34] reported that the pesticide distributors used to distribute products with labels written in foreign language, and in developing countries, farmers usually get information from pesticide vendors and from other farmers. The adverse risk was linked with lack of information about the products handled [35]. The most common practices of farmers in agricultural sectors are non-usage of personal protective equipment (PPE) and usage of worn-out PPE [36], exposure to pesticide due to unsafe pesticide storage [37] and improper way of disposal of empty pesticide containers [32]. The lack of education and poor knowledge on understanding the safe practices in pesticide application including storage, handling and disposal makes farmer at risk [36]. Higher level of education gives pesticide users better access to information and more knowledge of the risks associated with pesticides, and how to avoid exposure. In general, poorly educated farmers hampered in their ability to understand the hazard warnings on pesticide labels and guidelines recommended for safety application [38, 39]. Earlier studies have found that 68% of agrarian population reported the symptoms of sickness after routine pesticide applications and pesticide-related illness including skin problems and neurological symptoms [27, 40].

The Food and Agriculture Organisation (FAO) of the United Nations recommends that governments in developing countries promote pesticides that require little personal protective equipment [41, 42]. The improper use of pesticides can cause human poisonings, build up as residues in food and the environment, and lead to the development of resistance in pests [43]. Our recent studies have reported the presence of residues in various matrices [44] and reduced cholinesterase activities and DNA damage in farm workers [45–47]. The most frequently used pesticides in agricultural community belonged to WHO class II. Since farmers had poor knowledge about pesticide toxicity, the majority did not use appropriate PPE or good hygiene when handling pesticides. Several occupational uses of WHO class II pesticides and those of lower toxicity are seen in combination with inadequate knowledge and practice among the farmers. This poses a danger of acute intoxications, chronic health effects and environmental pollution. Training of farmers in integrated pest management (IPM) methods, use of proper hygiene and PPE when handling pesticides should be promoted [48].

1.7 Fate of Pesticides in the Environment

Unsafe use of pesticides can contaminate soil, water, air, vegetation and the entire environment. Despite killing insects or weeds, pesticides can also be toxic to other non-target organisms including birds, fish, beneficial insects and non-target plants. The fate of pesticides in the environment and its toxic effects are reviewed and described in the following section.

1.7.1 Contamination of Air

Pesticide sprays can directly hit non-target vegetation, or can drift or volatilize from the treated area and contaminate air, soil and non-target plants. The potential for exposure due to atmospheric transport and deposition of pesticides may create risks to living organisms including humans [49]. Airborne chemical contaminants are responsible for millions of annual premature deaths globally. Hazards associated with airborne exposure are several times greater than the hazards expected from other contamination [50]. Pesticide drift account for a loss of 2–25% of pesticide applied on field during every application, which can spread and travel several miles far away from the source of pesticide drift [51]. A large volume of applied pesticide can be volatilized within a few days of application. Despite the fact that only a few research studies have been carried out on these issues, studies continuously find pesticide residues in air [49, 52–54]. According to the USGS, the occurrence of pesticides in the atmosphere was detected in air samples collected in several areas of the USA [55]. Nearly every pesticide used in agricultural and other purposes has been detected in rain, air, fog or snow across the nation at different times of the year. Photochemical oxidation of pesticides in air will be very rapid, and these chemicals' interaction in the atmosphere influence the lifetimes [56]. Experimental designs and computer-based modelling related to emissions and dispersion of pesticides in air and ambient monitoring of air particularly in relation to opportunities to improve the data quality and their use in risk assessment will be most essential [57, 58].

1.7.2 Water Contamination

The atmospheric trace pesticide can interact with the moisture, and deposit from air during wet precipitation leads to contamination of surface water system [59]. Contamination of water by pesticides is widespread. A recent study conducted in Hooghly River basin in West Bengal, India indicates the presence of organochlorine pesticides and chlorpyrifos and its ecologic risk on aquatic animals. Traces of pesticides have been identified in water. About 44% of surface water was detected above the limit of quantification, and among these, 13% of samples exceeded the level of 100 ppb. The research investigations on river water across the word indicated that more than 90% of the samples tested for pesticides had one, or more often, several pesticides [60].

Several studies have reported the importance of pesticide monitoring in surface and groundwater system in order to regulate and assess the status of pesticides [61, 62]. Different types of pesticides were detected in waterways across the world, including 17 herbicides. The herbicides, namely 2,4-D, diuron and prometon, and the insecticides, chlorpyrifos and diazinon, are commonly used in urban home and school, as a result most often found in water. The USGS also found that concentrations of insecticides in urban streams commonly exceeded guidelines for protection of aquatic life. The herbicide 2,4-D was the most commonly found pesticide. Organochlorine pesticides such as endrin aldehyde, total BHCs and heptachlor exceeded the regulatory limits prescribed for groundwater in Pampanga River, Philippines. Surface water samples from Bhandara and Yavatmal region exceeded the EU (European Union) limit of 1.0 μg/L for sum of pesticide levels in surface water. Surface water often was found to be more contaminated with organophosphate and organochlorine pesticide than groundwater [63]. According to USEPA [64], pesticides exceeded standards for human health in ~10% of agricultural streams, ~7% of urban streams and ~1% of groundwater tested, whereas aquatic health exceeded in 57% of agricultural and 83% of urban streams. Similarly, 12% of groundwater in northern Spain exceeded the European Union (EU) directives regulatory standards [65].

1.7.3 Effect on Soil Fertility

Soil contaminated with pesticides can cause decline in populations of beneficial soil microorganisms [66, 67]. In general, loss of both bacteria and fungi leads to degradation of soil. Indiscriminate uses of chemical fertilizers and pesticides have effects on the soil organisms that are similar to human overuse of antibiotics. Overuse of those chemicals might work for a few years, but after awhile, there are not enough beneficial soil organisms to hold onto the nutrients [55]. Plants depend on a variety of soil microorganisms to transform atmospheric nitrogen into nitrates, which plants can use. Pesticide and herbicide applied in agricultural sector disrupt the soil condition and the normal process of plant growth. Many pesticides including 2,4-D reduce the efficiency of nitrogen fixation by the bacteria that live on the roots of bean plants [68, 69], reduce the growth and activity of nitrogen-fixing blue-green algae [44, 70] and also inhibit the transformation of ammonia into nitrates by soil bacteria [71]. The adverse effect of organochlorine and carbamate pesticides on beneficial microorganism including fungi is also reported [70].

1.7.4 Non-target Organisms (Fish and Wildlife)

A raising public awareness has come into force regarding the impact of pesticides after the publication of Book, Silent Spring by Rachel Carson [5]. This book highlighted the impact of pesticides on non-target organisms, birds, and contributed to the reversal of national pesticide policy. The nationwide ban on DDT and other similar pesticides stirred environmental movement that led to the creation of the US Environmental Protection Agency (US EPA) in 1970. Pesticides are found as most common contaminants in the environment including soil, air and water, and also on non-target organisms. As a consequence, they can harm non-target plants, fish, birds and other wildlife. Several recent studies highlighted the persistent nature of pesticides and its accumulation in various environmental matrixes such as fish [44, 71], birds [72, 73], bird eggs [74] and humans [75].

Toxicity of agrochemical such as atrazine affects the lipid peroxidation and activities of antioxidant enzymes in the freshwater fish [76] and increased immunoglobulin production in silver catfish [77]. Herbicide exposure to laboratory animal shows mitochondrial dysfunction and insulin resistance [78], and it also gives multiple stress effects on wetland zooplankton [79], fish and amphibian [80]. It was also reported that herbicide atrazine exposure affects the longevity, development time and body size in Drosophila [81]. Several cases studies on pesticide accumulation on dolphins have been reported [82–84]. Dolphins inhabiting riverine ecosystems are particularly vulnerable because of their habitats closer to point sources of pollution usualy caused by humans. Our recent study on fresh water fishes of bird santuaries in Southern India highlighted the presence of organochloirne pesticide residues [85].

1.8 Health Effects of Pesticide on Humans

Overwhelming evidences are available across the world on pesticide usage in agricultural field and its potential risk to humans and other life forms. Humans are exposed to pesticides through contact with the skin, ingestion or inhalation, and numerous negative health effects have been associated with these pesticides [30]. The acute toxicity of pesticides on humans is mainly due to interference with neural conduction by targeting voltage-gated ion channels or Na^{+}/K^{+} ATPase, interference with neural transmission by inhibiting acetylcholine esterase, stimulating respiratory sensory neurons or initiating pro-inflammatory signals. Pesticides are broadly classified into three categories based on their neurotoxic effects in mammals: 1. neural conduction interferer (organochlorine pesticides: DDE, DDE, cyclodienes, toxaphene, hexachlorocyclohexane, chlordecone and pyrethroid pesticide: pyrethrin and tetramethrin), 2. acetylcholine esterase inhibitor (organophosphate pesticides: parathion, malathion, methyl parathion, chlorpyrifos, diazinon and carbamate pesticides: aldicarb, carbofuran, carbaryl, ethienocarb and fenobucarb) and 3. pro-inflammatory stimulator (chlorophenoxy herbicide: 2,4-dichlorophenoxyacetic acid) [86]. No part of the population is completely away from pesticide exposure. The central and peripheral neural systems of the humans are affected who are exposed to high dose of OCs, OPs and pyrethroids [87]. The numerous negative health effects that have been associated with chemical pesticides (Fig. 1.1.) include dermatological, gastrointestinal, neurological, carcinogenic, respiratory, reproductive and endocrine effects. Additionally, occupational, accidental or intentional exposure to pesticides also leads to hospitalization and death [8, 88].

Occupational exposure to pesticide is considered as one of the high-risk groups. This group of workers are exposed to pesticides during production, formulation, spraying, mixing, loading and agricultural farm work [11, 89]. Farmers are routinely exposed to various types of agrochemicals, but there is no evidence about adverse effects posed by these chemicals on human health. Studies across the globe had shown adverse health effects of commonly applied pesticides in the agricultural sector. A significant relationship between occupational exposure to agricultural pesticides and the development of several diseases has been identified. It is quite common in agricultural community that they exposed to pesticide even when they are not directly performing tasks related to pesticide use [90]. Although studies on occupational exposure do not include all variables which can contribute to risk assessment, the real effects associated with agrochemicals are well established. It is more obvious that the agricultural community needs the implementation of a new

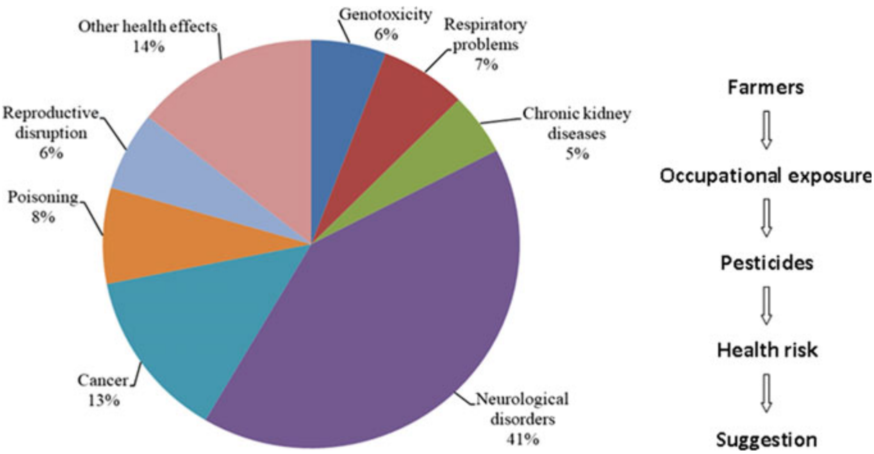

Fig. 1.1 Health associated with pesticide exposure among farmers. Adapted from Dhananjayan and Ravichandran [30]

agricultural concept regarding food production, which is safer for farmers, farm workers and the environment [30].

This section of review summarizes the recent findings interconnecting the association between occupational exposure to pesticides and related health effects on farmers in agricultural activities. Ye et al. [91] reported the evidence for an association between occupational pesticide exposure and asthma, and a perfect link between occupational pesticide exposure and chronic bronchitis or COPD among agricultural occupation. One of the studies at rural farming villages in Tanzania found a high potential for pesticide exposure with high frequency of self-reported acute pesticide poisoning and poor recording in hospital records [92]. Similar study at south-west Ethiopia reported health complications of pesticide exposure such as headache, nausea and vomiting, skin rash and irritation and abdominal pain [93].

Greenhouse workers exposed to pesticides showed increased counts of erythrocytes, leucocytes, platelets, haemoglobin, and genotoxicity and decreased cholinesterase, glucose, creatinine, total cholesterol, triglyceride and alkaline phosphatase [94–96]. A case-control study in the USA and Canada found an association between pesticide use and blood cancer risk [97]. An increased risk of death was reported due to non-Hodgkin lymphoma (NHL) among young farm-workers in southern Brazil [98]. Farmers in agricultural field found to have the highest prevalence of allergies, nasal congestion, wheezing and acute symptoms after pesticide use [99, 100]. Agricultural sector workers have reported numerous respiratory diseases such as chronic obstructive pulmonary disease, asthma [101] and interstitial lung diseases [102]. Children in close proximity to farms showed adverse respiratory system and the urinary metabolites of pesticides were associated with a decrease in lung function [103, 104].

Several findings provided important evidences on pesticide exposure and changes in neurobehavioral functioning in Chinese farmworkers [105] and neurodegenerative and neurodevelopment disorders [106]. Studies have also highlighted the alteration in thyroid function after long-term exposure to pesticides among male pesticide applicator [106], and poorer sperm morphology and lower luteinizing hormone (LH) among men [107]. Waheed et al. [108] suggested that dust contaminated with pesticides engenders significant health risk to the nervous and endocrine system, not only for occupational workers exposed to direct ingestion but also for nearby residential community.

Renal disease due to pesticide exposure provided reassuring findings of significantly increased risks among pesticide applicators [109, 110]. Migrant farmworkers in Thailand involved in spraying of pesticides have the increased risk of developing acute or chronic illness [111]. Over the past two decades, there has been an increase in chronic interstitial nephritis in agricultural communities. Existing studies provide scarce evidence for an association between pesticides and regional chronic kidney disease epidemics but, given the poor pesticide exposure assessment in the majority, a role of nephrotoxic agrochemicals cannot be conclusively discarded. Future research should be made with an assessment of lifetime exposures to specific pesticides with other major risk factors [112]. Several studies have reported that the low-level use of insecticides does not pose a risk to DNA in general [113]; however, recent studies have shown oxidative stress, DNA damage and lipoprotein peroxidation [47, 114].

Numerous studies have reported the associations between specific pesticides and bladder cancer risk, lung cancer, laryngeal cancer [101, 106, 115] and skin melanoma and multiple myeloma [116]. Further studies regarding this occupational exposure of farmers are needed, to determine the causes for the increased risk of this cancer, particularly in regions where there is an intense agricultural activity and where extensive pesticides are used. However, further studies warranted given the high burden and the ubiquity of these chemicals.

1.9 Controlled Release of Pesticides

Pesticide molecules are used worldwide for improving the agricultural productivity. However, these compounds and their degradation products show varying degrees of persistence and mobility in the environment and can have toxic, carcinogenic, mutagenic and teratogenic potentials, as well as effects on the endocrine systems of non-target organisms, including humans [117]. Variety of release systems applicable to the bioactive compounds in agriculture is given in Table 1.2.

Therefore, it is important for researchers to improve the usage rate of pesticides and to extend their duration of activity in the environment [118, 119]. Despite the fact that a sufficient amount of pesticides are typically applied during spraying, pesticide microemulsions, water dispersible granules and other traditional pesticide formulations usually below the effective concentration for controlling pests within a

Table 1.2 Variety of release systems applicable to the bioactive compounds in agriculture

Bioactive compounds with chemicals	Purpose of addition and observation	References
Silica and clay such as bentonites and sepiolite in agrochemicals	Activate the degradation	Grillo et al. [123] Barik et al. [124] Maqueda et al. [125]
Silica nanoparticles in drug delivery	Non-toxicity, low cost, high surface area and high reactivity as carriers	Dizaj et al. [126] Yang et al. [127] Wu et al. [128]
Nanotechnology in phytotechnology	For safe use and social acceptance of phytonanotechnology, the adverse effect and transfer of NPs in food	Wang et al. [129]
Lignin-based controlled release of pesticides	Lignin fragmentation and re-polymerization allow more control with flexibilities and improved properties of the modified lignin materials, and help achieve the desired control release outcomes	Chowdhury [130]
Emamectin benzoate (EMB)	EMB slow-release microspheres are an attractive candidate for improving pesticide efficacy and prolonging the control effects	Wang et al. [131]
Porous silica nanoparticles with abamectin	Improvement in photostability, water solubility, bioavailability and reduction in the residues of pesticides	Wang et al. [132]
Polymers: alginate and lignin, and synthetic polymer: polyhydroxyalkanoates (PHAs) with herbicides	Complete biodegradable, inexpensive	Reis et al. [133]
Polyhydroxybutyrate (PHB) and its hydroxyvalerate (PHBV) with herbicides	Complete biodegradable, isostatic and highly crystalline, and decrease in the speed of degradation	Amass and Tighe [134] Sudesh et al. [135]
Polyhydroxybutyrate (PHB) and its hydroxyvalerate (PHBV) with ametryn	The amount of herbicide released in the same period of time was significantly reduced (75–87%)	Grillo et al. [136]
Avermectin/polysuccinimide with glycine methyl ester nanoparticles (AVM-PGA) with avermectin (AVM)	To improve bioactivity and transportation	Wang et al. [137]

short period of time [118, 120, 121]. The loss of large amounts of pesticides in non-target areas is a serious threat to food security and the environment [122]. To mitigate the toxicity of these compounds in the environment, new and improved controlled release systems are emerging to increase the effectiveness of pesticide usage while minimizing their environmental impacts and aiding sustainable agricultural development.

The advanced controlled release systems can offer: (a) reduction in the amount of chemical substance required to protect crops; (b) diminished risk of environmental contamination; (c) reduction in energy consumption, since fewer applications are needed compared to conventional formulations; and (d) increased safety of the individuals who apply the product in the field.

Pesticide slow-release formulations provide a way to increase the efficiency of active components by reducing the amount of pesticide that needs to be applied. Slow-release formulations also increase the stability and prolong the control effect of photosensitive pesticides [131]. Currently, the silica nanoparticles as pesticide carriers did not show controllable porous surface properties, and release of pesticides was generally controlled by adjusting pesticides concentration and the thickness of coating layer, resulting in the relatively limited tuning range of release rate. Moreover, the size uniformity of silica nanocarriers needs to be further improved because monodisperse carriers are favourable to promote adhesion and permeability of the pesticide on target crops [131]. Nanomaterials (NM) serve equally as additives (mostly for controlled release) and active constituents. Product efficiencies possibly increased by NM should be balanced against enhanced environmental NM input fluxes. The dynamic development in research and its considerable public perception are in contrast with the currently still very small number of NM-containing products on the market. Nano-risk assessment and legislation are largely in their infancies [138].

1.10 Conclusion

Information on the occurrence of pesticide-related illnesses among agricultural populations in developing countries is insufficient. Therefore, descriptive epidemiological studies on the development of intervention strategies to lower the incidence of acute poisoning and periodic surveillance studies on high-risk groups are needed. Valuable information can be collected by monitoring the end product of human exposure in the form of residue levels in body fluids and tissues of the general population. The periodical education and training of workers ensure the safe use of pesticides. The occurrence of pesticide residues in various environmental matrixes contributes to the problems associated with pesticides. Pesticide contamination poses significant risks to the environment and non-target organisms ranging from beneficial soil microorganisms to insects, plants, fish and birds. The total cost–benefit picture from pesticide use differs appreciably between developed and developing countries. There is a need to convey the message that prevention of adverse health effects and promotion of health are profitable investments for employers and employees as a support to sustainable development of economics. Therefore, modern technology-assisted development in the application of pesticides is warranted in order to get the sustainable development in the agricultural sector and human well-being.

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