Chapter 4

Pesticides, the Environment, and Human Health

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/57553

1. Introduction

This chapter discusses the intricate web of interactions between human beings, pests, and pesticides in the 21st century against the backdrop of good environmental stewardship and economic sustainability. Pests and pesticides are defined and their effects on human beings discussed. Pesticides are defined as economic poisons with equal emphasis on "economic" and "poison". Pest control is differentiated from pest management and the factors affecting the tolerance of human beings for pests also discussed. Pesticides are used in agriculture to prevent or reduce crop *injury* and *damage* but their application is based on bioeconomic principles that help maintain good environmental quality as well as improve economic returns in farm enterprises. Even though environmental concerns were the impetus for the development of these bioeconomic principles, their significant economic benefits have overshadowed their environmental beginnings and function. The Economic Injury Level (EIL) is a bioeconomic concept that refers to the lowest population of pests that will cause economic damage, and the Economic threshold (ET), is the point at which action need to be taken in order to prevent an increasing pest population from reaching the economic injury level (EIL). Environmental EILs have been proposed to replace economic EILs in order to re-focus attention on environmental concerns without losing sight of economic considerations. Concerns on the environmental impact of conventional pesticides have led to increased interest in less toxic alternatives including biopesticides. The fact that these compounds are generally not as fast-acting as their conventional counterparts makes early pest detection even more crucial than in cases where conventional pesticides are used. The notion that organic pesticides are harmless and therefore can be used without safety precautions is erroneous and dangerous. In fact nicotine pesticides have been discontinued in many countries because they are very toxic to humans and rotenone another natural active ingredient is very toxic to fish and other aquatic organisms. Pesticides have also been implicated in the Colony Collapse Disorder (CCD) of native populations of honey bees, a situation that has made it necessary for some farmers in the United States to purchase or rent pollinating bees to ensure high yield and quality of certain crops. Behavior-based control of pests generally results in more effective use of pesticides and thus the reduction of pesticides released into the environment to combat pests. In pest management, behavioral toxicology encompasses elements of behavioral science and toxicology and refers to the effect of pest behavior on the performance of toxicants deployed against them; "behavior" in this case refers to pest behavior before, during, and after exposure to the toxicant (pesticide). Proper understanding and use of the principles of behavioral toxicology will result in more effective use of pesticides and a reduction in the quantity of active ingredients deployed against pests worldwide. Elements of Worker Protection Standards (WPS) and Personal Protective Equipment (PPE) in the use of pesticides are discussed. Important safety intervals such as the one between the last pesticide application and reentry into a field (reentry interval [REI]) and the minimum number of days between the last pesticide application and harvesting (pre-harvest interval [PHI]) are also discussed. In order to further ensure that all these safety regulations and precautions are followed, a number of retailers in the United States including Wal-Mart (largest retailer in the USA), require their food suppliers to have two major types of certification namely: Good Agricultural Practices (GAPs) and Food Safety certification. Both of these certification programs involve training of farmers on the safe and proper use of pesticides, pest management practices that reduce pesticide residues in/on farm produce, proper storage of pesticides and, proper disposal of pesticide containers. Farm audits are carried out to ensure compliance with regulations pertaining to each certification program; farms that pass these audits are certified. Fruits and vegetables in the United States that recorded higher than acceptable limits of various pesticides in calendar year 2011 are listed and the underlying farming practices discussed.

2. Pests, pesticides, and tolerance thresholds for pests

The objective of this chapter is not to revisit all the basic definitions of pests, pesticides and their effects on the environment as well as human health; it however, seeks to discuss the real but intricate web of interactions between human beings and their environment based on the realities of life in the 21ST century; this entire discussion will be against the backdrops of environmental sustainability and economic returns to human beings. The judicious use of pesticides in ways that are consistent with good environmental stewardship and sound business practice requires information on the elements involved in decision-making pertaining to pest management.

In order to comprehensively tackle pesticides and their effects on the environment there is an absolute need to start the discussion from the very source: pests whether real or perceived. The world's current attitude to pests does not give enough room for distinguishing between real and perceived pests; this is because the mere fact that an organism makes someone uncomfortable or presents some element of "nuisance" (the definition of which is also very elastic) makes it a pest. This concept will be better understood by taking a close look at what is defined as a pest. Pests generally exhibit one or a combination of the following characteristics: they compete with human beings for resources such as crops, livestock, forests, health, and recreational resources; they reduce the availability, quality or value of a human resource; they transmit disease(s); they constitute a "nuisance". Based on this definition it is crystal clear that "pest" is an anthropocentric designation. Examples of pest groups include: agricultural pests; medical pests, veterinary pests, and urban pests. Now that the "pest" concept has been appropriately identified as an anthropocentric one, it is important to note that the level of tolerance that human beings have for pests vary based on factors that include cultural norms, economic status, level of education, gender, sometimes age and setting (i.e. whether domestic or field). Some organisms are deemed to be pests in some cultures and in other cultures they are either considered to be good or innocuous organisms. Irrespective of the setting anecdotal evidence points to the fact that the richer someone is the less tolerant they are of pests in both domestic and farm settings. Small-scale farmers with limited resources are more inclined to tolerate insect pests on their farms than large-scale commercial enterprises, mainly because of the cost of pest management efforts. The scarab/dung beetle in the family scarabeidae in the United States is considered a beneficial insect from an ecological point of view because they help to recycle the feces of animals but from a non-ecological point of view they are considered nasty beetles because of their close association with feces and rotting bodies. In Egypt on the other hand the dung beetle was associated with the sun god and some accounts indicate that it was worshipped as a god.

Pesticides used in the control and management of pests have been defined in a variety of ways but most of these definitions share certain themes and elements in common. One of the major elements is that these products are designed to act against an undesirable life form (pest). The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of the United States defines a pesticide as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insect, rodents, nematodes, fungi, weeds or any other forms of life declared to be pests; it also includes any substance or mixture intended for use as a plant regulator, defoliant, or desiccant. In 1959 FIFRA was amended to cover other chemicals in the category of economic poisons which is the legal classification for a substance used for controlling, preventing, destroying, repelling, or mitigating any pest. The term "economic poison" is an interesting choice of words because it aptly describes pesticides. They are indeed poisons that serve an economic purpose defined by the users. It is extremely important not to overemphasize economic benefits of pesticides at the expense of their toxic properties or vice-versa. The correct use of pesticides is thus a balance between two quests: one of which is to achieve high economic/aesthetic returns and the other to reduce adverse effects on the environment and non-target organisms. According to Pedigo and Rice (2009) it is difficult to imagine a technology that would produce the amount of food and fiber and maintain the level of public health that we have today without pesticides. The authors quoted Dover (1985) who gave pesticides an apt description: "As their hazards become more apparent, so does the need to use them. Although designed to kill, they are often life savers. Although increasingly costly, they bring economic benefits. And while they have opened up many possibilities for improving agriculture and public health, they have closed others, making us extremely dependent on them for our continued survival".

3. Bioeconomic principles governing the use of pesticides and the concepts of pest control/pest management

The terms “pest control” and “pest management” are often used interchangeably even in technical literature pertaining to pests. These terms however denote different levels of tolerance for pests. The appropriate use of the term “pest control” is in instances when there is zero tolerance for a pest. This is usually seen in domestic settings; total elimination of the pest is the aim of anti-pest activities in such settings. An example that illustrates the zero-tolerance situation is a situation where a homeowner (with a morbid fear of snakes) reports the presence of venomous snakes in his house and invites an exterminator/pest control company to eliminate them. The homeowner will clearly not be impressed if the exterminator upon completion of this assignment reports that the number of venomous snakes has been reduced from 30 to 2 and that the exact location of the two snakes is unknown. Such a homeowner has a zero-tolerance for venomous snakes in a domestic setting, especially when their exact location is unknown. This is a situation in which the zero-pest tolerance is understandable and the objective is complete eradication of the pest. Pest control is the appropriate mindset employed in household settings, at ports of entry into an area (e.g. country), with newly introduced pests, and with pests that transmit diseases to human beings. This zero-tolerance attitude however is usually counterproductive in agricultural settings. This is because this mind-set or attitude renders a farmer or gardener (pesticide) trigger-happy to the point where far more money is spent trying to eliminate a pest than the financial cost of the damage that the pest is capable of causing). This indiscriminate use of pesticides leads to high pesticide loads in the environment and on farm produce, development of pesticide resistance in pests, and pesticide-related health problems in non-target organism including human beings. Pest management is the appropriate term and attitude in agricultural settings. It involves activities that aim at keeping the population or severity of pests within tolerable limits (or within limits at which they do not cause more economic damage than the cost of eliminating them); the anti-pest activities are mainly suppressive. In farming especially crop production settings, eradication of pests may not be practically and/or economically feasible. In crop pest management, a number of factors are taken into consideration in determining the profitability of using pesticides. An important part of this calculus is the total amount of damage or economic loss that the population of pests is capable of causing (Flint and Gouveia, 2001). Another important factor is the unit price of the farm produce which provides information on the expected income from the sale of the farm produce. The decision on use of pesticides is based on a cost-benefit analysis; cost in this case is in financial terms. An aspect of the cost that almost always receives very little or no attention is the environmental cost of deploying toxic compounds into the environment; these compounds reduce environmental quality and sometimes kill non-target organisms that may be innocuous or even beneficial. A good scenario that brings this concept home is one in which it has been calculated that a known population of stink bugs in a cowpea field are capable of causing a maximum of $200 worth of damage; as a farmer the question is whether you would invest money in spraying the crops with a pesticide which will cost you a total of exactly $200. At the risk of being over-simplistic the answer is no (from a financial perspective); the answer may not be so clear-cut from a biological/ecological perspective. This is because if the farm enterprise is going to lose $200 either through crop loss or through cost of pest management then the farmer might as well sit at home and rest instead of putting in all the effort just to lose the same amount of money. The issue however gets a little more complex if the biology of that particular pest is such that some type of pesticide treatment is required in the current season in order to prevent a severe build-up of the pest populations in the next growing season or subsequent years. In this case spraying the farm will result in no short-term financial benefits but appreciable long-term benefits. The cost of pest management/control activities using pesticides and the market value of the produce are always major considerations in the decision-making process.

This is an appropriate place to segue into discussions on the bioeconomic principles of pest management by first of all defining some of the basic terminology in this subject area. Pest status is one of the concepts that are very crucial in the bioeconomics of pest management. Information on the mere presence or occurrence of a pest in a crop production environment without information on its status is a recipe for poor pest management decisions. On the basis of pest status there are 1) sub-economic pests 2) occasional pests 3) perennial pests and 4) severe pests (Pedigo and Rice, 2009). The main distinguishing feature between these is the population of the pest relative to the lowest pest population that is capable of causing economic damage (this damage-causing population is defined as the Economic Injury level [EIL]). Pests are defined as sub-economic if their average population is so far below the economic injury level that even peak populations neither reach nor exceed the EIL. Occasional pests have average populations that are close enough to the EIL that occasional population peaks reach or exceed the EIL. In the case of perennial pests their average population is very close to the EIL and peaks routinely reach and exceed the EIL. The average population of severe pests is always above the EIL. Economic threshold (ET) in insect pest management refers to the pest density at which management action should be taken to prevent an increasing pest population from reaching the EIL; controlling pests at densities below this level usually does not make economic sense and usually costs more (financially) than the damage the pest would have done to the crop if it had been left alone. Knowledge of fundamental pest management strategies cannot be overemphasized. In addition to EIL and ET, there are other concepts such as injury, damage, and Gain Threshold. The objective of this chapter is not to focus on these principles and how the various formulae were derived; instead it seeks to discuss the elements of these concepts, their shortcomings, impact on the use of pesticides and impact on the environment. As previously defined EIL refers to the lowest number of insects that will cause economic damage. Economic damage is the amount of pest-induced injury that justifies the cost of applying pest control measures. According to Pedigo and Rice (2009), gain threshold refers to the beginning point of economic damage which is expressed in terms of amount of harvestable produce. It is also defined as the time when the cost of suppressing pest injury equals the money to be gained from avoiding the damage. Economic threshold also known as action threshold refers to the pest density at which management action should be taken to prevent an increasing pest population from reaching the economic-injury level. Damage refers to a measurable loss of host utility; this most often includes yield quantity, quality, or aesthetic appeal. Injury refers to the effects of pest activities on host physiology that are usually deleterious. The economic threshold and economic injury level can be summarized in the following formulae:

$ET = EIL \times C^{-t}$

Where

C = factor of increase in pest (population/severity) per unit time

t = time period expressed in weeks

By design ETs are set below the EIL to afford farmers/pest management professionals enough time to respond to a pest problem before it reaches the EIL.

The economic injury level can be calculated using the following formula:

EIL = Gain threshold x (Loss per insect x Amount of loss avoided)-1

EIL is also calculated using:

$EIL = >C \times (V \times I \times D \times K)^{-1}$

Where,

C = Cost of pest management per unit area.

V = the market value per unit of produce

I = injury units per insect per production unit

D = damage per unit injury

K = Proportionate reduction in potential injury or damage

In crop production settings, the Economic Injury Level (EIL) concept is commonly used with insect pests but with a number of disease problems, preventive sprays are recommended instead because once the field is infected it becomes too late to prevent damage which may result in major economic loss. It is however important to note that cost-benefit analysis needs to be done against the backdrop of the market price of the produce and the cost of management efforts. Based on the formula above anything that causes the economic injury level to go up will result in more tolerance for pests and reduced used of pesticides. Factors that can raise the EIL include low market value, low number/amount of injury units per produce per pest, and a low level of damage per injury. Consequently farmers are less inclined to tolerate pest activities, injury, and damage to high value crops relative to low value crops because the quantum of economic loss due to injury by the pests is larger. Generally the lower the level of injury per pest the more tolerant producers are of their presence in the field. If the potential reduction of crop damage is low (with the application of pesticides) farmers are less likely to use them. Crop varieties that are healthier and more resistant to the pests will record less damage and or less injury resulting in higher tolerance of the pest due to the resulting high EILs. This shows that good agronomic and cultural practices that result in healthier crops will result in more resistance to pests and reduced need and use of pesticides. It is wrong to assume that farmers always make pest management decisions based on bioeconomic indicators or at least rough estimates of the cost and benefits of pest management actions or inactions. There is a however a pesticide application practice usually observed among small-scale, limited resource farmers in countries where pesticides are readily available. This practice has been aptly referred to as "revenge spraying" by some authors. It involves late detection or at least late action against pest outbreaks in fields which results in crop injury and economic loss; farmers attempt a revenge against the pests by spraying pesticides at a time when this action does not save the crop. This results in further economic loss (cost of pesticide and labor required to spray the product) as well as the release of toxic materials into the environment (environmental cost). This practice is neither consistent with conventional EILs nor is it consistent with environmental EILs (explained later in the chapter). Depending on the biology of the pest, sometimes it makes sense to reduce the pest population in order to avoid more severe infestations in the subsequent seasons but in a number of cases this does not form the basis for the decision to spray.

The element of environmental cost in pest management is most often overshadowed by the financial costs. The goal of pest managers is to achieve zero damage/injury which means a K value of 1.0. Attempts to achieve this goal however results in overuse of pesticides and thus the deployment and possible accumulation of pesticides in the environment; environmental quality is thus reduced. It must also be noted that in integrated pest management it is usually wise to leave a sub-economic population of pests in order to sustain the natural enemy population instead of completely eliminating the pest; this ensures the availability of natural enemies to deal with the pest next time there is an outbreak. The issue of how much pesticide should be applied against specific pests on specific crops is spelt out in the label rate. Pesticide manufactures in their quest to avoid lawsuits due to treatment failure and in order to compete favorably with alternatives on the market, set their minimum label rates to be higher than what is required. This has driven some authors to suggest the use of environmental EILs as opposed to conventional EILs where environmental protection or safety is taken into consideration. According to Pedigo and Rice (2009), the goal in using in developing an environmental EIL is to determine the lowest pesticide rate to achieve a K value that is virtually equal to 1.00. As indicated earlier use of environmental EILs make pesticide applications more compatible with natural and biological pest control methods.

Environmental EILs can be calculated as follows:

$$EIL = C + EC \times (V \times I \times D \times K)^{-1}$$

Where EC = Environmental cost and the other variables are same as defined earlier for conventional EILs.

The tricky part of including the element of environmental cost is its measurement. According to L. Higley and W. Wintersteen (1992) indirect environmental cost can be determined by assigning monetary value to non-market goods such as environmental quality. The method suggested by the authors involves analyzing levels of risk of pesticides to environmental elements such as surface water, ground water, and non-target organisms such as aquatic organisms, birds, mammals and beneficial insects. The element of how much producers are prepared to pay in production costs is also very instructive and important; cost here refers to both the additional cost of using more environmentally safe but expensive pesticides and/or tolerance of higher levels of crop loss. It will also be more informative to consider how much consumers in general are prepared to pay for organic produce and generally crops produced using less environmentally toxic pesticides. An important perspective in pest management is that a number of pesticides can get the job done against a given pest but the final choice of pesticide must include environmental safety as well as the financial cost of the pesticide and its performance against the pest. A choice based solely on performance sometimes results in deleterious effects on non-target organisms (environmental cost) which action sometimes becomes financially costly either in the short or long term. Conversely choice of a pesticide based solely on environmental safety or low price tag without reference to its efficacy falls far outside sound business management. The crux of the issue is that a large percentage of farmers in developing countries engage in farming as a way of life and not as a business enterprise. This attitude towards farming results in poor decision-making which results in a continuous cycle of poverty. According to Pedigo and Rice (2009) there are limitations to the use of the EIL concept. These limitations have to do with the types of pests or injury, the specific pest management tactics selected, research requirements, and desirability of multiple inputs in making decisions. It is important to note that EILs are not helpful in decision levels for management of certain types of pests; in fact these decisions levels cannot be determined using the EIL in certain instances. There is often a lack of (or weak) quantitative relationship between damage and injury caused by such pests. It is difficult or impossible to put an economic limit on the control of pests that are of medical importance.

In the preceding discussion on pest tolerance the appropriate decision/action point from an economic perspective is the economic threshold (defined earlier). It is very important to note that in a farm setting the decision to deploy pesticides is based on economic thresholds which is not the case in domestic settings and other places where pest presence and activities result in aesthetic damage or emotional distress; in this case aesthetic threshold is the operative decision point. Accurate determination of aesthetic threshold is difficult and sometimes impossible because the threshold is not set based on logical reasoning or calculation. It simply reflects how tolerant an individual is to that pest and its activities. There are insects that do not cause economic damage or compete with humans beings for common resources but their mere presence even in very low populations result in appreciable emotional and psychological irritation. There are indeed instances in which the presence of such irritants (pests) is imaginary. *Delusory parasitosis* is a good example of this; it is characterized by the feeling of insects or other organisms crawling over the skin. In fact this situation has resulted in sufferers selling houses and cars far below the market value simply because they felt they were disposing of property infested with insects or mites that the best pesticides could not eradicate or eliminate. Aesthetic thresholds by definition vary from individual to individual and can be raised through education (Flint and Gouveia, 2001). Pest management specialists are called in every now and then to address a pest problem only to discover that the target organism is actually a beneficial one. Sometimes the tolerance of homeowners to such organisms increases when they are informed about their beneficial nature but sometimes they insist on total eradication from their premises. Such homeowners are well within their rights because irrespective of how beneficial the organism is if it causes the homeowner to be uncomfortable in his/her own home then it is a pest by definition. It is also important to note that pest control is a business and pest control professionals are not averse to treating an entire house even in instances where localized treatment could have eliminated the pest. This is sometimes because the homeowners specifically ask these professionals to "nuke" the entire house or financial considerations prevent some of these pest control professionals from recommending more targeted treatments which translate to less money for their efforts. There are also instances where pest control professionals heighten the level of intolerance or fear of an already agitated homeowner so as to encourage treatment of an entire house even in instances where the biology/ecology of the pest as well as its actual distribution in the structure/house show clearly that spot treatment or localized treatment is the most cost effective way to handle the pest problem.

There are some fundamental principles of pest management that constitute an integral part of good environmental and financial stewardship. In crop production there are four fundamental strategies: a) do nothing b) reduce the population of the pest c) reduce the susceptibility of the host d) reduce both the population of the pest and the susceptibility of the host. The "do nothing" strategy is usually a good option in instances where the pest has a sub-economic status, or in instances where cost of pesticide application outstrips the quantum of potential loss that will be prevented. This option is imperative in cases where total or close to total crop damage has occurred and pesticide application will only serve to further exacerbate the financial plight of the farmer. There are also instances in which the crops are ready for harvest and recommended pesticides have long pre-harvest intervals that will require that crops stay in the field for several days or weeks before harvest. A decision to use such pesticides results in crops not harvested at the recommended stage with concomitant adverse effects on their quality and shelf-life. Reduction of pest populations is usually done using IPM practices which include cultural practices, biological control, and use of pesticides. The susceptibility of host plants can be reduced by selecting resistant varieties.

4. Effects of biopesticides and conventional pesticides on the environment/non-target organisms

Natural pesticides are produced by processing natural substances. This group includes plant extracts (referred to as botanicals) and also mineral oils which are obtained when petroleum products are refined. These natural insecticides are classified into three broad categories: 1) biopesticides 2) botanicals and 3) biorationals (insect growth regulators). Biopesticides are pesticides derived from natural materials as animals, plants, microorganisms and certain minerals and have one or a combination of the following characteristics: 1) They have a natural occurrence 2) unique mode of action 3) low use volume and 4) have a narrow pest range.

A number of conventional pesticides are neurotoxins but most biopesticides have a mode of action that is unique. Low volumes of these products are usually effective against target pests; this reduces the amount of active pesticide released into the environment. This quality together with their biodegradable nature prevents the build-up of pesticides in the environment as is the case for some conventional pesticides. Possession of a narrow pest range reduces the probability of deleterious effects on non-target organism. In fact some microbial pesticides are so specific that they are affect only a target pest and closely related species. The relative specificity, the biodegradability, the low use volume, and the narrow host range render this group of pesticides more compatible in integrated pest management systems because of less impact on non-target organisms that may be beneficial. Issues of bioaccumulation and pollution of the environment are markedly reduced with the use of these products some of which are organic pesticides. This brings us to the point where the meaning of the word "organic" as used in "organic farming" or "organic pesticides" needs to be clarified. Clearly definitions of "organic" and "inorganic" from basic chemistry do not form the basis for classification of organic and conventional pesticides. In basic chemistry organic compounds are defined as carbon-containing compounds. This means that from a strictly chemical perspective, majority of conventional pesticides should be classified as organic pesticides because they contain carbon. Carbon-containing compounds such as DDT, chlordane and other cyclodienes are as conventional (inorganic) as pesticides come. It is important to note that the word "organic" in this usage refers to the view of the farm ecosystem as an organism with many functional parts working in harmony. The use of natural pesticides, biopesticides and botanicals is clearly consistent with this organismic view of the ecosystem/agro ecosystem; "organic" in this usage originates from this organismic concept. There is however, an erroneous impression that organic insecticides (some of which are biopesticides) are harmless and therefore do not require precautionary measures or protective clothing. This notion clearly needs to be dispelled because label instructions are for the safety of users and must be followed irrespective of whether the product is a biopesticide or a conventional insecticide. It is also important to note that some biopesticides such as those containing nicotine are very toxic to humans which has resulted in their discontinued use in many countries. Others such as rotenone are very toxic to fish and other aquatic organisms; the product has been used by South Americans as a fish poison since 1649. Some fish farmers use this poison to kill and clean out a pond prior to restocking them with new fingerlings. The use of pesticides containing rotenone as the sole active ingredient has been discontinued due to toxicity to fish and other aquatic organisms. There are however organic pesticides in the US market which contain rotenone as one of two active ingredients. Biopesticides are classified broadly into three main groups: a) microbial pesticides b) biochemical pesticides and c) plant-incorporated protectants. The positive attributes of biopesticides makes them popular with environmentalists and organic producers but it is important to note that not all biopesticides are compatible with certified organic production. Use of plant-incorporated protectants as is the case with transgenic crops (formerly referred to as Genetically Modified Organisms [GMOs]) renders them unacceptable as organic produce.

The use of more environmentally friendly products such as biopesticides and organic pesticides is associated with some drawbacks: generally organic pesticides are not as effective and or fast-acting as their conventional counterparts. Even though regular monitoring of fields and scouting for pests and other IPM practices are recommended for farmers who use conventional pest management methods, these practices are even more crucial for organic producers; this is because if pest issues are not prevented, reduced or detected early the pesticide options usually do not provide the quick and effective fix that conventional pesticides do. There are a few organic pesticides however, that compare favorably with their conventional counterparts in effectiveness and rate of action against pests. This situation introduces a tough choice between conventional pesticides that usually act faster, have longer residual activity, and are generally more effective and the more environmentally friendly natural pesticides (biopesticides, botanicals and mineral oils) on the other hand. The Environmental Protection Agency (EPA) in its quest to reduce pollution and toxic effects of pesticides on the environment, offered incentives to encourage the development of effective pesticides that had less adverse impacts on the environment. Generally it takes about a year or two to register a new biopesticide but it takes about 5-7 years to register a conventional pesticide. The reduced-risk pesticide initiative was introduced by the EPA to encourage the production of pesticides with less adverse impact on the environment; compounds with this designation receive priority in the registration process once they are approved. Given the millions of dollars that go into research into new active ingredients, formulation of pesticides, and efficacy trials (both laboratory and field), pesticide manufacturers are motivated to produce pesticides that are either biopesticides or reduced- risk compounds. Faster or expedited registration procedures for these pesticides offer pesticide manufacturers shorter periods between the development of the product and return on their investment. In the United States about 25% of pesticides are used in homes, gardens, lawns, parks, swimming pools and golf courses; lawns actually receive 10 times the pesticide dose that cropland receives. Heavy use of pesticides against pests on farms, in and around houses and recreational locations definitely has environmental and health costs on non-target organisms. Effects include morbidity and other behavioral changes that may not immediately culminate in death but affect the ecological r role of organisms in the environment; this sometimes lead to a cascading set of adverse effects that are sometimes difficult to trace back to pesticides.

5. Behavioral toxicology

Behavior has been described as the sequence of quantifiable actions involving cumulative effects of genetic, biochemical and physiological processes operating through the nervous system and aimed at maximal fitness and survival of the organism. It is a unique manifestation of the connection between the physiology and ecology of an organism and its environment (Little and Brewer 2001); this makes it a very important indicator of presence of toxicants and other environmental changes. Its usefulness as an indicator is further bolstered by what Kane et al. (2005) described as the nonrandom, highly structured and predictable sequence of activities associated with toxicity. To be relevant to toxicological assessments, behavioral responses must be: well-defined, measurable, ecologically relevant, and sensitive to a range of toxicants; the mechanism of response must also be understood. Behavioral endpoints that are represented across difference species of organisms and are capable of distinguishing between classes of insecticides with different modes of action are particularly ideal as indicators. The acceptance of behavioral endpoints as indicators of environmental toxicity in the United States began with the acceptance of avoidance behavior as legal evidence of injury to natural resources in 1986. This was under the proceedings of the Comprehensive Response, Compensation, and Liability Act of 1980 (NRDA 1986). The acceptance of other elements of behavior as indicators of toxicity marked an important milestone in the development of behavioral toxicology. Particularly noteworthy was the publication by the U.S. Environmental Protection Agency in 1991 listing behavioral response as a functional endpoint in neurotoxicity screening protocols. These behavioral endpoints have been used as early indicators of environmental pollution, but can be adapted for assessment of insecticide toxicity and performance. Behavioral toxicology refers to the impact of animal behavior/ecology on the effect of toxic compounds they come into contact with; it also refers to animal behavior after contact with toxicants. From the foregoing it is apparent that although the use of pest behavioral biology/ecology as the basis for successful pest management dates back several years, the development of the broader area of behavioral toxicology is relatively recent. The relevant elements of behavior span the period before, during, and after exposure to the toxicant. In the specific case of pests it refers to the effect of pest behavioral biology on the performance of pesticides deployed against them. It is important to re-emphasize the need to include behavioral symptoms of intoxication (i.e. behavior exhibited after exposure to the toxicant) in the broad definition of behavioral toxicology. A comprehensive definition of pest behavioral toxicology has to encompass exploitation of the natural behavior and ecology of pests to improve performance of pesticides; it should also include the use of well-defined and relevant behaviors for the assessment of pesticide performance. The contaminant does not necessarily have to be a pesticide and the exposure does not have to be deliberate. It is important to note that even though death is not a behavior most behavioral symptoms of intoxication culminate in death. This makes death induced by accidental exposure to toxic substances a very important indicator of environmental quality. In actual fact some organisms are so sensitive to toxic materials in their environment that their ability to survive in an environment is indicative of a low level of toxic materials in that environment. This is the basis for the use of organisms such as immature forms of mayflies as indicator organisms; their presence in a water body indicates a low level of pollution.

Behavioral toxicology is an aspect of both behavioral science and toxicology that is especially relevant in the control of subterranean termites and other social insect pests (Quarcoo, 2009). This type of termites present a good model for demonstrating the importance of pest behavior on the performance of pesticides deployed against them. The non-repellent termiticides that are commonly used in the United States are specifically designed to exploit various elements of termite social behavior to achieve optimum performance. These pesticides are typically slow-acting and non-repellent, allowing termites to continue their tunneling activities through pesticide-treated soil completely oblivious of the dangerous nature of the pesticides they are ingesting. The slow-acting nature of these pesticides serves the purpose of giving the foraging workers ample time to travel to their central nest to contaminate the queen who is responsible for laying the eggs. Foragers also groom each other and feed young termites, soldiers and the reproductive caste (i.e. King and Queen) through trophallaxis. Trophallaxis is the transfer of fluids including food by mouth-to-mouth (stomodeal) route or anus-to-mouth (proctodeal) route. These and other social interactions result in contamination of termites that have not had direct exposure to the pesticide. The behavior-based design of such pesticides results in a ripple effect that culminates in a high level of contamination/coverage of termites by the pesticide and thus results in better performance of these pesticides. Henderson (2003) studied the behavioral response of subterranean termites to treatment with two non-repellent termiticides:

http://dx.doi.org/10.5772/57553

Fipronil, and Imidacloprid. The neurotoxic effects of these pesticides and the underlying chain of reactions that result in the visible behavioral responses were discussed briefly. Su et al. (1982) compared the behavioral response of subterranean termites to three different categories of pesticides namely: repellent, slow-acting non-repellent, and fast-acting non-repellent compounds. Interestingly the termites sealed-off sections of their tunnels leading to areas treated with the repellent compound. Even though the same reaction was not reported for the fast-acting non-repellent compound, the high population of dead termites in the areas treated with this type of pesticide elicited avoidance behavior in the termite test subjects. Termites treated with the slow-acting non-repellent pesticide kept on tunneling into the treated zone and dead bodies were distributed all over the test arena as opposed to being concentrated in the treated zone as was the case for the fast-acting non-repellent compound. This resulted in the highest final mortality figures in the slow-acting non repellent treatment which was because there was neither avoidance behavior or sealing off of tunnels to the treated zone. The high mortality figures were also due to the slow-acting nature which afforded contaminated foraging termites ample time to interact physically and thereby contaminate other termites outside the treated zone. This study clearly demonstrated the effect of pest behavioral response on the efficacy of pesticides deployed against them. Another example of the importance of behavioral biology in pest management is when surveillance/sampling of pests is carried out during specific periods of the day when the pest is known to be more active which makes for easier sampling to determine the severity of the pest. The same principle is used in deploying contact pesticides which are usually sprayed during the period when there is a higher probability of direct contact between the pesticide and the targeted pest. Deploying a contact-type pesticide at a time of the day when the target pest is known to be hiding in a place that is either less or completely inaccessible (by the pesticide) renders a good pesticide less effective; this is especially so with pesticides that have a short residual activity. Lack of information on behavioral biology or lack of use of such information has resulted in treatment failures or the tendency of end-users to use higher than required quantities of pesticides to achieve desired results. Behavioral biology informs the choice of active ingredient and the best time to apply the pesticide formulations. It must be noted that the quest for higher levels of effectiveness and lower use volumes of pesticides involves targeting pests in their most vulnerable stage. Cockroaches that infest homes are generally known to like dark, humid, and warm environments (Pedigo and Rice, 2009) which explains their increased activity at night when the lights are off. A visual assessment of roach infestation carried out in a lighted room will result in an underassessment of the level of infestation. Behavior-altering chemicals such as female sex pheromones which are used by male insects to locate female partners for mating purposes is another tool that is employed against a number of insect pests. Typically it involves the production and use of synthetic analogs of female sex pheromones for a specific insect to attract its male counterparts into a receptacle where they are exposed to and killed by toxic strips (pesticides). Such pheromone are primarily used for pest detection but are sometimes used to cause significant reduction in certain pests through disruption of normal mating activities. The males spend so much time and energy looking for "superior or highly attractive females", as suggested by the concentrations of pheromones wafting to them. This leaves the males very little time to mate with actual females in the population. Some pheromone traps catch and kill sufficient male insect pests to affect the male to female ratio significantly enough to cause a reduction in reproduction resulting in significant dips in the pest population. It is important to recall that reduction in pest population is a fundamental strategy of pest management. Pheromone traps equipped with kill strips offer an environmentally friendly method of using pesticides without releasing them into the environment; as described these pesticides remain in the pheromone trap container. Hormoligosis is another interesting behavioral (mostly physiological) response to pesticides. It refers to reproductive stimulation of mites and some insects exposed to sublethal doses of pesticides; highest doses are recommended for such organisms (Pedigo and Rice, 2009). Low pesticides doses are used partly because the Environmental Protection Agency (EPA) regulations allow this practice primarily because of issues pertaining to the environmental fate, environmental cost, pesticide resistance, and financial cost of pesticides.

6. Safe use of pesticides and other pesticide-related good agricultural practices

There are two extreme views regarding pesticides but the most reasonable perspective is somewhere in the middle. One school of thought sees pesticides as products which cause havoc and must be avoided completely. The other end of the spectrum is the view that pesticides must be relied on solely to solve all pest problems and must be used every time there is even a hint of a pest problem. Those who hold this view either fail to understand the environmental cost associated with allowing pesticides to accumulate in the environment and/or hold the view that the ecosystem possesses such great recuperative capabilities to negate effects of intemperate release of pesticides into the environment. Neither the positive effects of pesticides on food production systems nor the health benefits derived from the control of disease vectors can be overemphasized. It is however extremely important that IPM methods are employed instead of the “identify and spray” method of pest management. Integrated pest management methods allow the use of other tactics in the management/control of pests so that even when pesticides become necessary the frequency of use and quantity deployed against pests is reduced.

Toxicity in all its forms (including environmental and direct effects on human health) should be reduced through the safe and judicious use of pesticides by following label and safety instructions. Restricted-use pesticides are available in most parts of the world but the enforcement of rules governing their use is lax in a number of countries (especially developing countries). Pesticide applicators (which are usually farmers) must be trained and licensed in order to qualify to buy and use restricted pesticides on their farms. These rules are enforced in a number of developed countries but same does not necessarily hold true in a number of developing countries. The situation is aptly captured in a publication by Eddleston et al. (2002) titled, “Pesticide poisoning in the developing world - a minimum pesticides list”. The authors reported that pesticide poisoning is responsible for more deaths than infectious diseases in some developing countries. Poor regulation of pesticides, dangerous pesticide

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handling practices, and easy access to pesticides make them a popular method of self-harm including suicide. The Food and Agricultural Organization (FAO) attempted to address this issue in 1985 by developing a code of conduct for the pesticide industry. Apart from voluntary nature of the code, inadequate government resources in the developing world rendered it ineffective; this is evidenced in deaths which still continue today. A typical example is the death of 23 students in India in July 2013 after eating lunch contaminated with an organophosphate pesticide. Annie Banerji and Mayank Bhardwaj (2013) were informed by medical doctors treating affected students that they were poisoned by an organophospate compound. Initial reports from the police was that the deaths were caused by cooking oil that had been kept in a container previously used to store an organophosphate pesticide. In some parts of the world, empty pesticide containers are re-used to store water, beverages of all kinds, and vegetable oils. Pesticide poisoning due to improper disposal and re-use of pesticide containers occur more frequently in developing countries than media reports suggest Adherence to the rules on proper disposal of pesticide containers (which is one aspect of the pesticide training) could have averted this disaster. The World Health Organization (WHO) recommended that access to highly toxic pesticides be restricted; countries that followed this recommendation recorded lower suicide rates than what obtained previously. As indicated earlier in most developed countries, special licenses/permits are required in order to purchase and use restricted pesticides. Restricted-use pesticides are essentially a group of pesticides whose toxicities and modes of action render them too dangerous to be handled by untrained and uninformed people. A number of authors have advocated for this type of system to be put in place in developing countries. The development of a list of less dangerous pesticides for use in IPM systems is expected to result in fewer pesticide-related deaths in developing countries. In the United States, some pesticides are covered by a federal regulation called the Worker Protection Standard (WPS) which are designed to protect agricultural workers and people who handle pesticides from pesticide injury (EPA, 2013; Pedigo and Rice, 2009). WPS are used in addition to the specifications on the pesticide label. This law targets crop consultants/pesticide applicators; farm-owners/managers; and individuals/firms which contract and offer labor services on farms, forests, and greenhouses. The WPS provides specific instructions on personal protective equipment, Restricted-Entry Intervals (REIs), and other safety provisions all of which aim at protecting pesticide users from pesticide injury. REI refers to minimum amount of time that must elapse before workers can re-enter a field that has been sprayed with a pesticide. Personal Protective Equipment (PPE) for deploying pesticide include coveralls (or a long-sleeved shirt and long-legged trousers), neoprene boots and gloves, goggles/face shield, respirator, and a wide-brimmed hat. Trousers should not be tucked into boots but should be worn outside the boots to prevent direct assess of pesticides to the feet through the wide brims of these boots; pesticides can also roll off the trousers into the boots if they are tucked into the boots. Gloves should be unlined so that they can be properly washed.

In the United States the Department of Agriculture (USDA) has a set of guidelines on Good Agricultural Practices (GAPs) for farmers (USDA-AMS, 2013). The GAP guideline functions as a second level of impetus for farmers to follow recommended farming practices to ensure the production and supply of nutritious and wholesome food. Large retail shops including

Wal-Mart (which is the largest retail shop in the United States) insist that farmers who supply them with all kinds of farm produce to be GAP-certified. The GAP certification process involves training sessions to ensure that farmers understand the practices that lead to the production of safe and nutritious food for consumers. The aspect of GAP that is most relevant to the subject under discussion is training of farmers on the proper storage and use of agro-chemicals including pesticides. Another important aspect of the training covers the proper disposal of pesticide containers. USDA-GAP requires farm operations to use pesticides and other pre- or post-harvest materials in a manner consistent with prevailing regulations and the label instruction; this includes following state licensing requirements for pesticide applicators. Farm record-keeping is an absolute must for participation in the GAPs and Food Safety certification programs. Food safety audits are usually performed when crops are being harvested so that auditors can actually observe the range of farm activities to see if they tally with the food safety plan for each farm. The auditors inspect farm records pertaining to the type of pesticides used and date of application; with this information auditors can easily determine if harvesting is within the Pre-harvest Interval (PHI) or after the interval. PHI refers to the minimum numbers of days that must elapse before crops can be harvested from a field after they have been treated with a chemical product (pesticide). Unsafe pesticide residue levels result when PHIs are not adhered to. The market-driven requirement to use pesticides correctly and to test farm produce for pesticide has given farmers the economic impetus to get on board these programs. The increased popularity of pesticides in developing countries makes it imperative that regulations be put in place or existing ones enforced to ensure that consumers are provided with safe and wholesome food.

The practical definition for conventional pest management in developed and developed countries used to differ significantly; the increasing popularity of pesticides in developing countries is bringing the definitions a lot closer with time. The fact that food safety programs are neither enforced by Governments nor required by retailers in a number of developing countries puts consumers in a very unsafe place. In some countries there are no retailers of farm produce with the size and clout to economically enforce this food safety practices. This is partly because the marketing system for farm produce in these countries involves several very small-scale retailers or direct purchase of produce at the farm-gate. The large retailers in the United States require GAP-food safety certification of the farmers who supply them with produce. Food safety certification involves a complete audit of all farm operations to ensure the production of fruits/vegetables that are not contaminated with pathogenic organisms. Farms that engage in any type of irrigation are required to test the irrigation water for pathogenic organisms such as coliforms which indicate contamination with manure and harmful pathogens (Rangarajan et al. 2000). Farm produce are also sampled for pesticide residues to ensure that they are within acceptable limits. Pesticide residue values outside the acceptable limits are indicative of improper or excessive use of pesticides. These certification programs also involve unannounced post-certification audits/inspections to ensure that GAP and food safety practices are being followed. It has been observed that more and more retailers are requiring these types of certification in order to be eligible to supply them with farm produce. Other developed countries have their own versions of these certification programs

http://dx.doi.org/10.5772/57553

but it appears as if a number of developing countries either lack such programs or fail to effectively use them. Wal-Mart recently started an initiative to buy fruits and vegetables from sources that are as close as possible to each outlet. In furtherance of this initiative, the retailer has been working very closely with researchers and Extension specialists at Tuskegee University in the United States, to train limited-resource farmers on GAPS, Food Safety, IPM and a range of other areas relevant to the production of fruits and vegetables. This trend of retailers taking the driver's seat on issues pertaining to safe and proper use of pesticides as well as pesticide residues on farm produce is a step in the right direction.

As indicated earlier, pesticides are economic poisons and must be treated as compounds that perform a great service when used properly; improper use on the other hand sometimes leads to losses that far outweigh their benefits. Adverse effects including death of non-target organisms including those beneficial in agroecosystems are some of the unintended effects of pesticides even when used correctly; improper use of these products exacerbates these effects. The colony collapse disorder (CCD) of honey bees has been attributed to the use of pesticides with some active ingredients receiving larger shares of the blame than others. Yang et al. (2008) reported that imidacloprid impairs the foraging behavior of honey bees. The authors exposed honey bees to different concentrations of imidacloprid (dissolved in dimethyl sulfoxide) and a control (50% sucrose solution [(wt: vol]). The study revealed a dose-dependent effect on the behavior of honey bees; they reported delays of at least 1.5 h in the return of some of the bees treated at low concentration whereas all the bees treated with higher concentrations of imidacloprid (i.e., 4,000 and 6,000 μg/liter) went missing. Lingering effects of imidacloprid-poisoning among returning bees resulted in foraging behavior that was markedly different from what was observed prior to treatment. Yang et al. (2008) also reported a positive relationship between concentration of imidacloprid and onset of abnormal foraging behavior and an inverse relationship between concentration of the pesticide and percentage recovery of bees. Certain concentrations of these pesticides somehow affect the homing system in bees. This is just one example of a practical demonstration of the effect of some pesticides on beneficial organisms but the jury is still out on whether CCD can be attributed exclusively to pesticides. Irrespective of the cause, the declining population of native bees has resulted in businesses in the United States which produce pollinating bees for sale to farmers. Some of these businesses rent out honey bees to farmers for crop pollination and still get to harvest the honey produced by the bees. Other businesses sell bumble bees for pollinating crops such as watermelons. Financial investment in pollinating bees in an evolving agro ecosystem where farmers can no longer depend on natural bee populations has forced farmers to pay closer attention to selection of pesticides that are compatible with plant pollinators. Some of these businesses have carried out their own research on the effects of various pesticides on bees which information is made available to customers. Using a symbol system, farmers are informed which pesticides are incompatible with the bees, which ones require that the hives be moved out of the field, which ones require that the hives be closed before spraying but opened a day later and which ones can be sprayed without even closing the hives.

First-hand experience with farmers has revealed a few mistakes that are sometimes made with respect to the use of pesticides. There are a number of erroneous views: first of all the fact that a product is labeled for use against a specific pest does not necessarily mean it is labeled for use on all crops attacked by that pest. The fact that a pesticide is registered for use in the United States does not guarantee that it can be used in the United Kingdom. In fact there are pesticides that are registered for use in some states in the US but are disallowed in other states in the same country. Some pesticides such as herbicides are registered for use on specific crops planted by direct seeding and are not registered for use on transplants. Use of these products for purposes for which they have not been registered constitutes off-label use of the product which is a crime in the United States; these are crimes irrespective of whether this is used inside the user's house, backyard garden, or commercial farm. In countries where this has not been declared a crime there is a need to consider that option; this option should be preceded by intensive public education on pesticide use and safety. Another observation is that some farmers wait too long to report pest problems to Extension specialists; this is usually because of failure detect the pest problem early due to lack of or infrequent pest surveillance (monitoring) activities. There are also instances where the problem is detected early but precious time is lost trying various recommendations from well-wishers who are not qualified to offer advice on these issues. This results in pest situations in which investments can either not be redeemed at all or the farmer is left no other option apart from the use of pesticide that are very effective but come at high environmental cost. This statement is not intended to discourage farmer to farmer education but to state that issues pertaining to the use of economic poisons need to be verified because once deployed they cannot be "unsprayed" and if the treatment fails then economic loss from the cost of pesticide treatment adds to the crop loss to result in an overwhelming vortex of economic loss.

7. Pesticide residues in fruits and vegetables and effects on human health

In order to effectively discuss the subject of pesticide residues a couple of terminologies must be defined. No Observable Effects Level (NOEL) refers to the level where no observable effects of the poison can be detected in experimental animals. The Acceptable Daily Intake (ADI) refers to the amount of chemical residue which is not thought to pose any appreciable risk to an organism even with a lifetime of daily exposure. This level is usually set a thousand fold or more less than NOEL (Pedigo and Rice, 2009).

In 1958 an amendment referred to as the Delaney clause, was made to the Food Drug and Cosmetic Act in the United States. The Delaney Clause disallows any cancer-causing chemical (carcinogen) on food for human consumption. In the quest to reduce exposure of consumers to pesticide residues, the Pesticide Data Program (PDP) was initiated in 1991 to collect data on Pesticide residues in food (USDA-AMS, 2013). The program currently plays an important role in the implementation of the 1996 Food Quality Protection Act (FQPA). The FQPA directs the U.S. Secretary of Agriculture to collect pesticide residue data on commodities most frequently consumed especially by children and infants (USDA-AMS, 2013). Two U.S. federal agencies namely the EPA and the Food and Drug Administration (FDA) use the PDP data. It is used primarily by the EPA to assess the dietary exposure during the safety review of existing pesticide tolerances (also called Maximum Residue Limits); the FDA uses it to assist in planning commodity surveys for pesticide residues which is done from an enforcement/ regulatory perspective. In the US, farm produce (mainly fruits and vegetables) with the highest pesticide levels have become known as the “dirty dozen”. The dirty dozen includes: apples, celery, cherry tomatoes, cucumbers, grapes, hot peppers, imported nectarines, peaches, potatoes, spinach, strawberries, and sweet bell peppers. Kale/collard greens and summer squash find their way onto the list when it is expanded to cover the 14 most pesticide-laden food items. Levels of pesticide residue exceeding the EPA tolerance levels are shown in (Table 1). These high pesticide residues are generally due to a variety of reasons including: inadequate knowledge or use of IPM practices. Farmers usually find themselves having to spray more than the recommended rates because pests are not targeted at their most vulnerable stage and so require higher quantities of pesticides (active ingredients). It is also possible that poor record-keeping by some farmers makes it difficult for them to follow pre-harvest intervals for the pesticides. When crops are harvested within the PHI, pesticide residues tend to be higher. Some of the farmers may not be calibrating their sprayers properly or may be mixing more than the recommended rate of the pesticides. Pesticide resistance by pests is another reason why high pesticide residues are recorded. This is because farmers feel compelled to continue using a product that has worked well for them in the past; this continues to the point where pesticide resistance develops and higher quantities of the product have to be sprayed in order to achieve the desired results. The demand for blemish-free fruits and vegetables contribute to the high pesticide residues in food.

Sometimes pest pressures are so high but so is the consumer demand for blemish-free produce. Some farmers spray more than the recommended amount of pesticides or spray more frequently than recommended in order to ensure blemish-free produce. There are also instances where high pesticide residues are due to drift of pesticides from aerial sprays (using aircraft) on neighboring farms during windy conditions; in these instances the farmers are not aware that more than the required amount of pesticides are getting to their crops. Excessively high rainfall periods also result in more fungal diseases which are usually dealt with using preventive (calendar) spray regimen which may sometimes be excessive. Metabolites of Captan fungicide on snap beans must be watched carefully based on the percentage of detections (9.2%). The relatively high percentage of detections of bifenthrin (19%) on cherry tomatoes and 5.7% detections each of dinotefuran and acetamiprid and sweet bell peppers deserve closer attention. Apart from bifenthrin on cherry tomatoes, the percentage detections are generally low but all these figures are an impetus to reduce the percentage of detections. In a number of developing countries restricted-use pesticides are imported with labels that show this designation very clearly but sale of these products is not restricted to people who have restricted-use pesticide permits; in fact these permits do not even feature in any discussion at the point of sale. Pesticide residue analysis also not the norm in a number of developing countries; there is therefore no way of telling the level of pesticide residue on farm produce in these countries. It must be noted however, that in some of these developing countries, pesticides are not used that much or in some rural communities they are not used at all resulting in farm produce that are basically organic.

Vegetable	Pesticide	Range of Values Detected (ppm)	EPA Tolerance Level (ppm)	Percentage of Samples with Detections
Cabbage	Acephate (Insecticide)	0.033	Not listed	0.1
Cantaloupe	Acephate (Insecticide)	0.017 – 0.054	0.02	0.3
Frozen Spinach	Acephate (Insecticide)	0.21	0.02	0.6
Sweet Bell Peppers	Acetamiprid (Insecticide)	0.002 – 0.22	0.20	5.7
Cherry Tomatoes	Bifenthrin (Insecticide)	0.007 – 0.16	0.15	19.1
Snap Peas	Chlorfenapyr (Insecticide)	0.004 – 0.034	0.01	0.8
Frozen Spinach	Cyhalothrin (Insecticide)	0.026 – 0.092	0.01	1.0
Snap Peas	Cypermethrin (Insecticide)	0.038 – 0.27	0.1	4.4
Snap Peas	Deltamethrin (Insecticide) Includes Tralomethrin	0.020 – 0.19	0.05	1.5
Sweet Bell Peppers	Dinotefuran (Insecticide)	0.010 – 0.81	0.7	5.7
Sweet Bell Peppers	Fludioxonil (Fungicide)	0.040	0.01	0.1
Hot peppers	Tetrahydrophthalimide (Metabolite of Captan Fungicide)	0.015 – 0.065	0.05	0.9
Snap Beans	Tetrahydrophthalimide (Metabolite of Captan Fungicide)	0.006 – 0.37	0.05	9.4
Snap Peas	Thiamethoxam (Insecticide)	0.003 – 0.12	0.02	2.2

Culled from the USA Calendar Year 2011 Annual Summary of the Pesticide Data Program (USDA-AMS, 2013)

Table 1. Fruits and Vegetables in the USA with Pesticide Residues above the EPA Tolerance Levels in 2011.

In conclusion the human population in the world is continuously increasing and unless certain changes are made, the earth's resources (which are dynamic) may not be able to sustain this growing population indefinitely. Viewing and treating the earth's resources as "infinite" is erroneous, dangerous and unsustainable. In order to slow down or prevent our arrival at that carrying capacity it is important to achieve higher yields of crops and other food items per unit area of land. There are a number of ways to achieve higher yields including the use of transgenic crops (formerly known as GMOs) and pesticides. Transgenic crops have been developed to have characteristics including: drought resistance, pest resistance, pesticide resistance, and higher yields per unit area. Transgenic crops are however not accepted in all parts of the world for a variety of reasons but world food production needs to be increased one way or the other to feed the growing world population. The stance against transgenic crops in developing countries will become very untenable in the near future unless other improved farming methods are introduced to make up for the short-fall in food production. This is because in a number of these countries a large percentage of farmers lack the necessary managerial skills and technological capabilities to optimize the use of resources (farm inputs) in order to have high yields of good quality crops to feed their growing populations. In developing countries a combination of zero-tolerance for pesticides and zero-tolerance for transgenic crops without any improvements in the technical know-how and managerial skills of farmers as well as access to advanced farm equipment will only result in major shortfalls in food production. The fact that the use of pesticides will keep growing (at least in the foreseeable future) makes it imperative to continue research efforts to identify new pesticide chemistries with less adverse effects on the environment. It also makes it very important that pesticide users all over the world learn to use these products safely and properly in the spirit of good environmental stewardship. The use of IPM methods will help to greatly reduce the reliance on pesticides and hopefully slow down the rate of environmental pollution. The use of examples of regulatory framework for pesticides in the United States is not to suggest that it is the most perfect system in the word or the archetype for developing structures in other parts of the world; it is however important to take note of the level of effectiveness of these structures as well as the specific demographic, cultural and other characteristics of different parts of the world in order to design or improve existing regulatory structures for pesticides.

Acknowledgements

The authors will like to express their sincere appreciation to the George Washington Carver Agriculture Experiment Station (GWCAES) of Tuskegee University and USDA-NIFA for co-sponsoring research and outreach activities (through the Statewide Extension IPM Coordination Program Grant); these activities informed the content of this chapter. Our appreciation also goes to Wal-Mart for its iniative to collaborate with Tuskegee University to support and invest in the development of limited-resource farmers to produce selected crops and providing a guaranteed market for same; observations and outcomes from this project and other Extension IPM projects informed the content of this chapter.

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