PESTICIDES AND CHEMICALS THAT IMPACT AGRICULTURE

Implications for the feed and rendering industries

INTRODUCTION

Agriculture has greatly benefited from the discovery, development, and use of a broad range of pesticides and industrial/commercial chemicals. However, their wide-spread use, together with their unique physical, chemical, and biological properties, have raised concerns among the American public regarding their adverse impact on human health and the environment. This paper provides a brief summary of the past, present, and future of these chemicals and how their presence impacts agriculture in general, and the rendering and feed industries in particular.

As shown on Table 1, the word pesticide represents a general term to describe a number of categories of chemicals that indicate their function as related to the target species they are designed to control. For example, insecticides are active against insects such as ants and bugs, while herbicides are active against weeds and other plant life, rodenticides are active against rodents such as rats and mice, disinfectants are designed to destroy or inactivate bacteria, fungicides are active against mold spores, acaricides are designed to kill mites and ticks, and antifouling compounds are used to prevent barnacles, algae, and other marine life from growing on the bottoms of boats and ships. The industrial and commercial chemicals include a wide range of solvents, monomers, plasticizing, agents, etc., as shown in Table 1. Many of these substances also have important uses in the agricultural industry.

PESTICIDES

As indicated in Table 2, the U.S. Environmental Protection Agency (EPA) has defined pesticides in general as "any substance intended or preventing, destroying, repelling, or mitigating any pest". The intent of any compound developed and used as a pesticide is to stop the growth or end the life of a wide range of living organisms that man considers to be pests. Hence, pesticide chemicals are specifically designed as neurotoxins, development or reproductive toxins, hormonal toxins, desiccants, etc., for a given target organism.

History of Pesticides

The concept of pesticides and their use to control the existence of unwanted living organisms traces back to 1000 B.C., when sulphur was used as a fumigant in China. As shown in Tables 3 and 4, a wide range of compounds which are well known to us as toxic agents, have been used as insecticides, rodenticides, fungicides, herbicides and other pesticides from the year 1500 A.D. to the present time.

In the 1930's, modern synthetic chemistry was born and companies were busy developing and experimenting with chemical substances that would effectively destroy a specific target organism. In 1939, 32 pesticide products were registered with the U.S. Department of Agriculture for use in the United States. During this same year, Paul Mueller, a Swiss Chemist, discovered the active properties of DDT on insects. During the 1940's, the phenoxy acid herbicides were developed, as where fungicides and the gaseous fumigants CS_2, ethylene oxide, and methylbromide. During this same period, DDT became widely used as the principle agent against insecticides. During the 1950's and 1960's there was rapid development and use of other organochlorine insecticides, as well as the development and introduction of the organophosphate insecticides for use against insects. However, during the 1950's, adverse effects that were eventually traced back to pesticides and in particular DDT, were being observed in nature. The relationship between DDT and the shell thickness of eggs from wild birds due to changes is calcium metabolism was documented. Because of the fragile nature of eggs from birds contaminated with DDT, the mortality rate of embryos increased dramatically and the U.S. populations of wild birds, including American Eagles, was decreasing at a significant rate. These observations and other concerns regarding the environmental impacts of pesticides beyond their intended function prompted Rachel Carson to write the book "Silent Spring" which focused America's interest and concern for the first time on the mounting environmental problems linked to pesticides.

However, in spite of the concern for the observed adverse effects in nature, the development and use of pesticide chemicals continued to grow, and by 1987 there were over 1,200 active ingredient pesticide chemicals, and over 37,000 commercial pesticides products registered with the U.S. EPA. Although there has been a reduction in the number of registered active ingredient pesticide chemicals and formulated commercial products since 1987, the total U.S. annual volume of pesticide usage in agriculture, as well as the individual volumes of herbicides and insecticides, remained about the same through 1995. As shown in Table 5, the annual pesticide usage in the United States for agricultural purposes in 1995 was estimated to be 939,000,000 lbs. with herbicides and insecticides representing the leading individual categories of usage. Four crops, corn, soybeans, cotton and wheat represent the principal agricultural applications for a large number of the insecticides and herbicides. Also, by 1995 the total annual pesticide usage for non-agricultural purposes reached over 60,000,000 lbs. for each of the home and garden use and industrial and commercial use categories. The annual usage volumes for these categories are shown in Table 6.

Pesticide Properties of Concern

As research efforts and the subsequent development and introduction of new pesticides continued, other investigative efforts were underway in an attempt to identify the hazards of pesticides and their residues in the environment. Table 7 identifies the major properties of pesticides, and particularly organochlorine pesticides, that are of concern from the standpoint of human health and the environment. Many pesticide chemicals are acutely toxic and can cause serious health effects with only short-term exposure to specific levels of the substances. Another property of concern is their resistance to degradation. While this is advantageous from the standpoint of their applications as pesticides, it is a major concern from the human health standpoint since the resistance to degradation translates to persistence in both the environment and in all living things, including humans. Again, long-term persistence is associated primarily with organochlorine pesticides. However, although organophosphate pesticides are not expected to persist and thought to be more readily metabolized and excreted from the body, this general category of pesticides (organophosphates) is comprised of a heterogeneous group of compounds, many of which are also chlorinated. Therefore, concerns regarding potential residue contamination must be addressed on a chemical-by-chemical basis. Further, although many of the organophosphate chemicals exhibit more rapid degradation, the huge volume of usage continually supplies the environment with measurable quantities. As a result, there is a ubiquity of these substances in the environment in addition to the organochlorine pesticides, which results in the contamination of ground water, surface water, rain, snow, fog, soil, vegetation and crops. These media in turn represent major avenues of exposure to humans and lower animals, primarily through the food chain..

In order to better understand the properties resulting in adverse health effects and the specific chemical classes of pesticides that exhibit these properties, one must first review briefly the classification of pesticides based on chemical structure. A very brief summary of the important classifications from the standpoint of the rendering and feed industries and of human health are shown in Tables 8 and 9. The organochlorine insecticides are easily classified because they represent specific hydrocarbon structures in which substituted chlorine represents the only substituted groups. Because of their parent aromatic and aliphatic ring structures and their highly chlorinated structures, they tend to be highly resistant to degradation and therefore are highly persistent in the environment and bioconcentrate in all living things. For example, the use of DDT was banned in 1972 and yet measurable quantities of DDT and its metabolites (p,p′ DDE) are still found in animal tissues destined for human consumption 27 years later. The organophosphates represent another important class of pesticides both from the standpoint of application and use in agriculture and also in terms of concern for human health and the environment. As previously mentioned, this category of pesticides represents a very heterogeneous group of chemicals with varying properties and behavior. The other important classes include the herbicides because of their chlorinated structures in many instances, their broad applications on plant life, and their huge production volume. Fungicides are important in that they include the chlorinated phenols as a class of chemicals. Chlorinated phenols have been demonstrated to represent one of the important intermediate chemicals in the inadvertent formation of the polychlorinated dibenzo-p-dioxins (PCDDs). One chlorinated phenol, pentachlorophenol, is actually classified under wood preservatives. The PCDDs are considered to be one of the most toxic substances known to man.

Toxicity of Pesticides

Table 10 summarizes some of the important acute and chronic toxic effects of organochlorine pesticides. In terms of acute toxicity, they tend to affect the central nervous system although the exact mechanism of acute toxicity is not known. Their effect in overstimulating the central nervous system is obvious when one looks at the various clinical signs and symptoms including hyperexcitability, hyperflexia, tremor, dizziness and convulsions. The single most important chronic toxic affect of organochlorines is their carcinogenic properties. Chronic toxicity results from long-term exposure to extremely low doses, which is highly characteristic of substances that produce tumors (cancer) over a lifetime of exposure. It is this property of carcinogenicity that has been the principal force in banning the use of the organochlorine pesticides. Additionally, other neurological disorders are also seen as chronic toxic effects, and they include tremors, headaches, dizziness, and with substantial exposure, loss of consciousness and epileptiform convulsions. More recently, many of the organochlorine pesticides have been identified as potential or possible endocrine disrupters. This represents a large group of suspect chemicals that are thought to serve as either imitators of normal estrogenic and androgenic hormones or as blockers of hormonal receptor sites on target organs in the endocrine system. These types of adverse effects would create major problems, particularly in the areas of adverse developmental and reproductive effects.

The acute toxicity and mechanism of action of organophosphates, and carbamates is well known (Table 11). In this case theses substances inhibit the activity of a substance called acetylcholine esterase, which regulates the transport of nerve impulses from one nerve cell to the other at a location known as the synaptic junction. When the acetylcholine esterase is inhibited, the levels of acetylcholine present in nerve cells is not regulated and continues to permit the uncontrolled transport of nerve impulses across cells leading to serious neurological disorders. These range from restlessness, ataxia, confusion, and memory loss, up to more serious effects such as violent convulsions, cyanosis, coma, and death. Less is known about the chronic toxicity of organophosphates. However, it is known that acetylcholine esterase inhibition can occur after repeated doses at lower levels. Additionally, there is evidence of delayed, persistent, and latent effects in humans and delayed effects in animals. Reports indicate a synergism among certain organophosphates such as malathion and O-ethyl O-p-nitrophenyl phenylphosphonothioate (ENP). Other studies suggest that certain organophosphates may be converted either in the environment or the body (i.e., in vivo) to metabolites with potentially greater toxicity than the parent compound. This group also contains a number of chemical substances with possible endocrine disrupter properties.

Early Regulation of Pesticides

Approximately ten years after the publication of "Silent Spring" by Rachal Carlson, the federal government took action and cancelled all agricultural uses for DDT. At that time, only its use for public health emergencies was retained. As shown in Tables 12 and 13, many other registrations were cancelled and/or uses banned on a wide range of pesticides during the subsequent 17 years. These cancellations were intended to substantially reduce the risks of pesticides to human health and the environment. It is interesting to note that those pesticides listed in Tables 12 and 13 that have an asterisk represent substances that are still found today at residue levels in agricultural products and in the tissues of meat destined for human consumption. This provides clear support to the known properties of resistance to degradation and persistence of these chlorinated substances in the environment and in all living things.

Table 14 reflects the impact of the regulatory actions to ban or control the use of many of the pesticides during the 1970's and 1980's. This table shows that the 32 pesticide products registered with the USDA in 1939 increased more than one thousand-fold to approximately 37,000 products and 1,200 active ingredients by 1987. The effects of the bans and restricted uses is clearly evident in the reduction in the number of active ingredients between 1987 and the present. The data show a reduction by approximately 50 percent in both active ingredient chemicals and numbers of pesticide products registered. However, it is important to note that the overall U.S. volume of use for all pesticides has remained approximately the same since 1987. As a result, the U.S. Congress has had major concerns regarding pesticide use, pesticide distribution in the environment, and its effect on the general population, and in particular, children and infants.

Food Quality Protection Act of 1996 (FQPA)

In 1988, Congress requested the National Academy of Sciences (NAS) to establish a committee under the National Research Council (NRC) to study the scientific and policy issues regarding pesticides in the diets of infants and children. In 1993, the NAS published its report entitled "Pesticides in the Diets of Infants and Children". As can be seen in Table 15, the overall conclusion reached by the NAS NRC Committee was the presumption that children and infants, in the absence of data to the contrary, were at greater risk of adverse health effects from pesticides than adults. This conclusion was based on the greater consumption of food per unit body weight, a different selection of foods consumed, a greater potential of exposure to pesticides from non-food sources, differences in the ability to activate, detoxify, and excrete xenobiotic compounds, and the lack of data on pesticide toxicity in developing organisms such as infants and children. Although the NAS Committee found that quantitative differences in toxicity between children and adults are usually less than a factor of approximately 10-fold, they concluded that differences in diet and thus dietary exposure to pesticide residues account for most of the differences in health risks from pesticides between children and adults.

The concerns of Congress, as indicated in Table 16, included the adverse health effects on the human population, and in particular the adverse effects on children and infants. They were concerned also with the ubiquity of pesticides in the environment and the chronic adverse health effects that result from long-term exposure to low levels of pesticides. Additionally, their concerns focused on the fact that the principal exposure to pesticides came from food, water, and residential exposure. In August of 1996, Congress passed the Food Quality Protection Act (FQPA) (Table 17). This act significantly amended the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) and the Federal Food, Drug and Cosmetic Act (FFDCA). The clear intent by Congress was to significantly reduce the amount of pesticide exposure in human foods, particularly in the case of infants and children. Among many other provisions, the Act calls for reassessment of all tolerance levels allowable on raw agricultural commodities for all registered pesticides. At present that relates to greater than 9,000 individual tolerance levels on approximately 600 registered active ingredient pesticide chemicals. Approximately 1,000 of the tolerance levels specifically involve organochlorine and organophosphate pesticides. The Act further mandates that at least one-third of the total of over 9,000 tolerance levels will be reassessed by August of 1999, that two-thirds of the tolerance levels will be reassessed by the year 2002, and that all 9,000 plus tolerance levels will the reassessed by the year 2006. In addition, the FQPA mandated that special consideration should be given to the health of children and infants by adding a special safety factor of ten-fold on their behalf.

As shown in Table 18, published tolerance levels are not new and have been applied to a wide range of food products including vegetables, fruits and meats and other animal products such as milk and eggs. For example, there are tolerance levels for 136 pesticides, 126 pesticides, and 88 pesticides in the fat of cattle, hogs, and poultry destined for human consumption, respectively (Table 19). This does not include the no published tolerance levels ("zero" tolerance level) for all other registered pesticides. Many of these tolerance levels were established by EPA during the 1980's and the early 1990's. Congress has now mandated under FQPA that these tolerance levels be reassessed in light of an additional safety factor of ten-fold to protect children and infants. As a result of this reassessment, it is anticipated that many tolerance levels may be lowered substantially or revoked entirely and that certain pesticide registrations may be cancelled.

As shown on Table 20, the establishment of tolerance levels for pesticides and foods is not solely based on the toxicity of the substance. First, the no-effect level in humans for toxic effects is determined. This is referred to as the "Reference Dose", or "RFD". This value is then considered within the context of the necessity of the use and quantity required for each pesticide as well as the estimate of exposure from all sources including food, water and residential pesticide applications. Considering all of these factors, the tolerance level is then established. For determining the toxicity of a given pesticide, the no-observable-effect-level or NOEL is determined in test animals under controlled experimental conditions (Table 21). The NOEL is then adjusted by a ten-fold safety factor for interspecies variability in order to ensure that humans are adequately protected (adjustment from animals to man). That value is again adjusted by an additional ten-fold safety factor for intraspecies variability. This adjustment is made to account for all sensitive and susceptible individuals within the human population. However, under the new Food Quality Protection Act (FQPA), Congress has mandated the application of an additional ten-fold uncertainty factor to specifically protect children and infants. This additional safety factor may be reduced to three or eliminated altogether if there is convincing scientific evidence that children and infants are not more susceptible to the toxic effects of the specific pesticide chemical in question. These decisions are made on a chemical by chemical basis by the EPA's Tolerance Reassessment Advisory Committee (TRAC).

The impact of the reevaluation of tolerance levels may result in a certain number of tolerance levels remaining unchanged. However, it is anticipated that tolerance levels for most pesticides (70 to 80 percent) will be lowered or revoked (Table 22). In the case of those tolerance levels that are revoked, or given "zero" tolerance levels, there are consequences that are of importance to the rendering and feed industries (Table 23). First, the definition of a "zero" tolerance level in a food is based on the minimum quantifiable level that can be achieved analytically in a food sample. Hence, this level is close to the limit of detectability of the pesticide in various foods. Secondly, if a pesticide or a food with a "zero" tolerance contains a pesticide at the minimum quantifiable level or higher, the food is considered to be adulterated. Accordingly, the regulatory statutes are clear that it is illegal to move adulterated food in interstate commerce. Therefore, it is absolutely critical that feeds and feed ingredients fed to animals do not contain pesticides at levels that would cause the published tolerance levels or the "zero" tolerance levels to be exceeded. In summary, the overall regulatory approach to pesticides under the Food Quality Protection Act is for EPA to reassess the tolerance levels for all foods, for FDA to enforce the tolerance levels for most foods, and for USDA to enforce the tolerance levels for meat, poultry, and certain egg products and also monitor tolerance levels for these foods (Table 24).

INDUSTRIAL AND COMMERCIAL CHEMICALS

In addition to pesticides, there exists a wide range of industrial and commercial chemicals that find their way into the environment, and therefore, have the potential to enter the food chain. Many of these environmental contaminants have been identified by EPA and are included in routine analytical tests conducted in conjunction with environmental impact studies and other environmental assessments (Table 25). These routine analyses include tests for volatile organic chemicals (VOCs) which addresses 33 separate chemicals, chemical categories or chemical classes, semi-volatile compounds which include 64 chemicals or chemical classes, pesticides which include insecticides, herbicides, etc., seven PCB products, polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), 75 chemicals or chemical classes that are suspect endocrine disrupters, and 56 chemicals, chemical classes or chemical categories that have been identified as persistent, bioaccumulative, and toxic, and are referred to as the "PBT list".

Table 26 indicates the wide range of industrial and commercial chemicals, summarized by category of use, that are produced for particular applications. This list is by no means complete and many other use categories include chemicals that may enter the environment. In addition to these "man made" chemicals, there are numerous substances that are naturally occurring or inadvertently produced under certain conditions. These also include compounds that are formed as a result of the presence of certain precursor substances and the availability of heat as a catalyst. Recent reports have indicated the existence of chlorinated dibenzo-p-dioxins as a natural contaminant of certain bentonite clays that have been mined and used to aid in the free-flowing of soybean meal for poultry feed. The best example to illustrate the heat catalysis would be the formation of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans which has occurred both during chemical processing and as a result of combustion. With respect to the former, chlorinated dibenzo-p-dioxins were shown to be formed during the manufacture of the defoliate "Agent Orange" that was used in the Viet Nam war. This dioxin contaminant of the herbicide was subsequently reduced by adjusting the temperatures and pressures applied during the synthesis of these products. Another example is the formation of chlorinated dioxins and chlorinated furans in municipal incinerators where there is an availability of PVC products and other sources of chlorine in addition to high temperatures which serve as a catalyst for their formation. The most significant example of chlorinated dioxin formation for the agricultural industry, was the formation of dioxins in fleshing grease which caused the original "chick edema" problem in 1957. Another important source of potential chemicals that can enter the food chain is the unintentional chlorination of the wide range of compounds. We have seen some evidence of the formation of such chlorinated compounds in our laboratories during the routine screening of materials used in the feed industry. With respect to the plausibility of inadvertent or unintentional chlorination of certain compounds, we can look to the huge volume of chlorine and hypochlorite compounds that are used to disinfect potable water and waste water as well as their use as a bleaching disinfectant (Table 27). This volume of chlorine use exceeds 2.3 billion lbs. per year and supports the current hypothesis that many chlorinated substances can be formed unintentionally at trace levels and eventually enter the food chain as residues in tissues destined for human consumption. The concern for this possibility is further reinforced by a consideration of the concentration of such chlorinated substances and man-made chlorinated industrial/commercial chemicals from water into recovered oils as shown in Table 28. Since most chlorinated hydrocarbons are fat soluble or "lipophilic" substances, they tend to dissolve in the recovered oil. Hence, such chlorinated compounds can concentrate up to 1,000-fold in the recovered oils. As a result, substances in water at parts per billion levels, generally below limits of detectability, may be concentrated to parts per million levels in oils and would be of concern as chemical residues in edible tissues. The rendering and agricultural industries should be acutely aware of the possible or potential contamination of feeds and feed ingredients with industrial and commercial chemicals, either man-made or inadvertently produced, and should take appropriate steps to prevent major problems from occurring.

SUMMARY

In summary, the implications regarding pesticides and industrial/commercial chemicals for the rendering and feed industries can be reduced to four general areas (Table 29). First, these industries should anticipate lower pesticide tolerance levels for most food products and as a result, a greater concern for the levels of pesticides and chlorinated hydrocarbons in all feeds and feed ingredients. This includes those pesticides for which "zero" tolerance levels have been or will be established and a consideration of what levels in feeds and feed ingredients will result in residue levels that exceeded the "zero" tolerance levels. The second area relates to an increased focus on organophosphate pesticides. Although certain companies routinely test their products for organophosphate pesticides, this practice is generally not followed by rendering companies to the same extent as the screening for organochlorine pesticides. With the reduced tolerance levels, this focus on organophosphate pesticides will be important. The third area is an increased awareness of the potential for industrial and commercial chemicals to enter the food chain. This includes both those substances that are "man made" as well as those that are inadvertently produced as a result of special conditions that promote their synthesis. And finally, the fourth area relates to a greater need for the analytical laboratory to develop and utilize analytical methodologies that ensure limits of detectability on feeds and feed ingredients that will prevent levels in meat, poultry, milk, and eggs to exceed the new tolerance levels. Also, analytical laboratories must develop and use more comprehensive screening methodologies to accommodate not only a larger number of organochlorine pesticides, organophosphate pesticides, and their metabolites, but also to include those additional non-pesticide industrial and commercial chemicals that have a high likelihood of appearing in the food chain.