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Chapter 1

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Evolution of Pesticide Use

History provides many examples of human activities which, when conducted in an ill-judged or ignorant manner, within a few years become a threat to human existence. It is what Albert Schweitzer, German theologian, philosopher, physician and Nobel Prize winner (1952) warned us about. His words are quoted in the well-known book by Rachel Carson, *Silent spring*: “Man has lost the capacity to foresee and to forestall. He will end by destroying the Earth.” Plant protection chemicals, also known as pesticides, constitute an example of such a threat which has been present for many years in the social consciousness. Contemporary science tries to answer the question of how much these fears are justified. Although modern plant protection products have little in common with their quite unsuccessful precursors, such as DDT, there still exists a growing amount of evidences proving that these types of synthetic chemical compounds contribute to various disorders in biocenose organisms and in human health.

Pesticides belong to various groups of chemical compounds characterized by a specific chemical structure which, as so-called active substances, are included in the composition of commercially available products. Their basic feature is toxicity, or the ability of the substance to evoke chemical damages and in consequence, the death of the organism. This damage consists most frequently in blocking the activity of certain enzymes or hormones controlling important vital processes. This means that pesticides belong to the group of substances which are dangerous for living organisms – which includes not only harmful organisms but also any others which happen to be within the range of pesticide activity. In practice, natural mechanisms of total resistance of organisms to specific pesticides occur very rarely, and the notion of selectivity is of a quantitative character – this only means that harmful organisms are destroyed to the larger extent than those that are considered beneficial. This phenomenon is the main reason for biodiversity reduction in biocenoses subjected to chemical anthropopression.

The toxicity of a chemical compound is not a constant feature – it depends on the species, its individual sensitivity, the method by which the poison enters the organism, the time of exposure and on other factors. The basic criterion of pesticide toxicity is the LD_{50} index. It determines the individual dose of poison which causes the death of 50% of organisms in a given group within a specified period of time.

Laboratory research on animals also involves determination of the Acceptable Daily Intake (ADI) – an index specifying the maximum amount of a specific substance that according to the current state of knowledge can be ingested every day over a lifetime, without any likely negative health results. Determination of ADI is based on establishing the so-called no-effect level for the most sensitive of the examined species of animals.

The literature often quotes data provided by the WHO, reporting the deaths of 20,000 people in a global scale (mainly in developing countries) caused by pesticides. What is much more difficult to assess are the results of poisoning the organisms by sub-lethal doses of pesticides, particularly when applied over extended periods of time, which include mutagenic, teratogenic, carcinogenic, immunotoxic, embriotoxic and behavioural changes. This is particularly important with the current chemization of the environment by chemicals of different mode of action. Hormonal effects, may be good example for it. Unlike typical poisons, which reveal a linear character of activity (an increased dose of the substance leads to a stronger effect), compounds that cause disorders of neurohormones and hormones fulfilling the role of chemical information transmitters show completely different mechanisms. In this case, a lower dose is usually more harmful, and a critical phase is a foetal period, when a sudden differentiation of the organism takes place. It also concerns the risk to human health. This is proven by examples of combining exposure to pesticides with an increased risk of the occurrence of certain tumours in both humans and in animals. Epidemiological research for example conducted in various countries has also demonstrated an increased frequency of the occurrence of congenital defects in children of parents with prior contact with pesticides.

Until recently, a high rate of pesticides consumption was a measure of agricultural progress. For example, in the 1990s, it amounted to 17.1 kg/ha in the Netherlands, 10.8 kg/ha in Belgium, 4.5 kg/ha in Germany and in France, and 0.6 kg/ha in Poland. Nowadays, these tendencies have been reversed, and the programmes of sustainable use of pesticides which are currently introduced in the European Union plan further limitations with a reduction of the area of its application. In 2003, it amounted in Poland to 1.1 kg/ha of cultivable land, while in the EU it averaged 4.6 kg/ha, with much higher usage rate in fruit and vegetable farming than in field crops. A beneficial phenomenon, from the point of view of environmental protection, was the very low participation of pest control products, both in the EU and in Poland.

Many studies have shown that modern methods of pesticide applications in the form of spraying are very wasteful, since only about 0.3% of the applied dose of the active substance reaches the site of its operation or is taken up by the harmful target organisms, while the remaining part constitutes a harmful or unnecessary burden to the environment. Nevertheless, it should be borne in mind that environmental contamination by pesticides is also unavoidable beyond the area subjected to the treatment.

Risks caused by chemicals to environment is connected with their movement from place of treatment. According to various sources, the drifting range of plant protection products in aviation treatments can reach up to 50% of the applied dose. This phenomenon occurs to a much lower extent with the use of ground sprayers (1-

30%), although it can sometimes be significant. Large losses can also occur as a result of product evaporation; sometimes they reach 80-90% within a few days after the treatment. Against this background, a marginal importance is attached to surface runoff (about 2%), which rarely reaches the value of 5-10% of the preparation dose.

Currently applied crop protection products typically demonstrate a limited persistence if the preparation is applied in small doses and over a large area. Under these conditions, its dispersion and degradation, modified by the effect of abiotic and biotic environmental factors, happens quickly. Much more serious threats exist with spot emissions of toxic substances to the environment, an example of which were pesticide dumps built in 1971-1981, in accordance with the laws in effect at that time in Poland. Particularly unfavourable properties of certain pesticides include high durability and the ability to bioaccumulate (this concerns particularly organic connections of chlorine) and lack of selective activity. This latter factor is related mainly to the contact toxicity of crop protection products against insects, which is caused in these organisms by a high rate of the body surface to its volume. Also, water organisms are very sensitive to pesticides since, because of their nature, they are "doomed" to having permanent contact with various chemical substances within their living environment for the entire period of their development. One should also bear in mind the mutual relations between organisms in biocenoses which, in the case of biodiversity reduction caused by chemical treatment, can mean a reduction of food base for some of them. What is also significant is the increasing evidence of selection among harmful organisms in their susceptibility to pesticides (known as resistance) which, given the frequent application of specified active substances, is becoming a major cause of treatment ineffectiveness. This phenomenon was found for the first time in 1914, when the resistance of a harmful pest of orchards, San José scale, to a lime sulphur solution was revealed found. It currently remains one of the most important problems in crop protection.

The most important factors taken into consideration while assessing the effects of pesticides on the environment include:

1/ dosage of the active substance applied, place and conditions for performing the treatment,

2/ active substance content in air, soil and water,

3/ speed of pesticide degradation in each of the above mentioned parts of the biotope,

4/ pesticide toxicity against different species of organisms.

Regardless of ecological costs of treatment, it is known that chemical plant protection activates typically from 1/5 to 1/3 reserves embedded in agriculture. This is particularly visible in horticulture crops which are characterized by much larger use of pesticides than farming fields. According to various assessments, on a global scale, about 30% of potential crop yield is destroyed by diseases, pests and weeds, to which 15% of losses occurring during storage and transport should be added. However, assessments carried out by the Institute of Plant Protection in Poznań (Poland) prove that the problem is not that clear-cut. For example, it was demonstrated that losses in beetroot yield due to abandonment of chemical protection can range in various years from 1.4% to 100%, although in the case of other plant species, the differences can be much lower. Questions about the future of chemical plant protection are therefore very well-founded.

Pesticides, in the literal meaning of this word (Latin *pestis* - plague, pest *caedo* - kill) are poisons used to eliminate organisms which are harmful and undesirable in agrocenoses and during the storage period of crops. This type of compounds are also applied outside agriculture in order to destroy harmful organisms, *e.g.* as products used for premises disinfection, wood preservation, pest elimination in living premises, animal parasites. A basic criterion for pesticide classification is its intended use. Accordingly, the following types of pesticides can be distinguished: zoocides – products for control animal pests, which are divided into insecticides (intended for insect control), acaricides (acarids), nematicides (nematodes, plant parasites), molluscicides (snails), and rodenticides (rodents). A separate group consists of herbicides, as weed control products, and fungicides, used to prevent fungal diseases. Some of them are intended only for luring (attractants) or deterring (repellents) certain living organisms, while the others affect vital processes of a crop plant, *e.g.* supporting its resistance, although such substances constitute a relatively small part of crop protection products.

The oldest, most differentiated group of plant protection products are insecticides. References to their application can be found in the very distant past. As results from the present status of knowledge, the first human beings appeared on the Earth about 3 million years ago, while the history of insects is at least 250 million years old. We can only suspect that primitive man used various available methods as repellents to deter troublesome insects. The first documented records as regards measures used for control pests date back to 2500 BC, when the Sumerians used sulphur compounds with an unpleasant smell to rub the skin as protection against insects. In ancient Assyria, around 2000 BC, farmers were obliged to provide an appropriate number of locust eggs and insects. The best known and the oldest medical document of the ancient Egypt, known as “Ebers papyrus”, dated to about 1550 BC contains about 800 recipes, which include various substances acting as poisons or pesticides. In order to protect grain in granaries, the Egyptians used fat from cats and birds, smoke from burnt gazelle excrements and some mineral salts. According to Homer, about 1000 BC, people knew the procedures of fumigating premises against insects by burning sulphur, which also became a precursor of the sulphur fungicides used until today (it was used to fumigate wine skins). More or less at the same time, in China, various substances containing mercury and arsenic were used to control lice in humans. As early as in 1200 BC, the Chinese used lime, sawdust, street dust and insecticides of plant origin to protect seeds against pests and, since about 200 BC these included arsenic products.

An example of an early biological method was the application of predatory ants to protect citrus orchards against caterpillars and wood pests, while lines and bamboo rods put over the tree branches to facilitate ant movement can be regarded as the oldest known form of integrated pest control. Theophrastus of Eressos (about 370 - 287 BC.), a Greek naturalist and philosopher, known as the father of botany, observed that certain species of weeds accompanied selected plants. He claimed that wild trees were less attacked by pests than cultivated trees, while those that had aromatic wood were not damaged at all. He also described a method of tree destruction by treating their roots with olive oil. Soon after that, a Roman politician and writer, Cato the Elder (234 - 149 BC), recommended the application of black hellebore oil (*Helleborus niger*) to control rodents and insects. Olive pomace with the addition of salt, cooked in copper vessels, was used against ants, moths and caterpillars feeding on cabbage. This method of control weeds was also recommended by Marcus Terentius Warron (116 - 27 BC), who was considered to be one of the best educated persons in ancient Rome. Other methods recommended at those times included seed dressings with sediments from wine pressing and bovine urine.

Pliny the Elder (23 - 79), in his "Natural History" reports the use of arsenic against harmful insects, although in practice, this measure, because of its properties – a chemical compound deprived of colour, smell and taste – was rather used as an ideal poison for people. Palladius, living in the 4th century AC, recommended the use of an owl's heart or sprinkling the earth around the garden with ash or chalk as the measure ant control, and moistening seeds with caterpillar blood before sowing them as protection against caterpillars. A barefoot woman with wind-blown hair, walking around the garden in the morning, at dawn, was the best method for repelling caterpillars from the garden. The efficiency of many of such methods of protection against pests and diseases can be regarded as quite doubtful. It is not surprising, then, that the ancient Romans eagerly celebrated a spring festival of Robigalia, established by the legendary second king of Rome, Numa Pompilius to appease Robiga and Robigus – the pair of gods looking after crops and protecting it against rust. On that day, April 25 of every year, a procession of the followers proceeded to the sacred grove, where a priest sacrificed a red dog.

In the Middle Ages, besides such proven methods for pest control as burning cuckoo feathers against flies, mosquitoes and spiders, fumigating cabbage plants with a mixture of wine with sulphur or fumigating plants with burnt powder of animal horns and hoofs, there were also other more unconventional methods of protection in the form of church anathemas and court judgements. For example, the locust was forbidden to damage the poor, it was ordered to move to other fields or leave the area. It was only in modern times that examples of a more rational approach in this regard appeared. They were supported by the revolution in agriculture which took place in Europe in 1750-1880. At that time, harmful insects were mainly controlled against with the use of plant-derived preparations. These were most frequently decoctions of tobacco leaves, extracts, or dried and ground pyrethrum flower heads (*Chrysanthemum cinerariaefolium*) as well as rotenone - obtained from the roots of tropical plants belonging to the *Lonchocarpus* or *Derris* genera. Particular attention should be paid to pyrethrum, which has been known since ancient times as a strong poison in the form of a powder of chrysanthemum inflorescence of a contact effect (initially as "Chinese" and later "Persian" and "Dalmatian" powder). In modern times, pyrethrins contained in pyrethrum are precursors of a known group of insecticides – pyrethroids.

In 1883, in the USA, an aqueous solution of calcium polysulphide known as lime sulphur was used for the first time to control fungal diseases (particularly powdery mildew) and red spiders in orchards. Due to its high phytotoxicity and reduction of assimilation capacities of plants, this product ceased to be used in productive orchards in Poland many years ago. An accidental discovery in 1885 in France of the fungicidal properties of slaked lime with copper sulphate, known as Bordeaux mixture, help to control *Plasmopara viticola* plaque. This substance became a precursor of fungicides applied until today, based on copper oxychloride. The first successful seed dressing applied in the 18th century to control fungal diseases was mercuric chloride, known as sublimate – a very toxic substance, accumulating in soil, later used as a disinfectant in medicine. At the end of the 19th century, sublimate, as a substance of high efficiency against corn-smut, was returned to, for a short time, along with a strong disinfectant – formalin. Since 1915, the shift in the assortment of seed dressings was observed towards less toxic (although still very harmful to the environment) organic mercury compounds. The final withdrawal from the use of mercury seed dressings occurred in the 1960s. Soil pathogens were controlled with the use of chlorinated hydrocarbon compounds – hexachlorobenzene and pentachlorobenzene which are very toxic for soil fauna. They were replaced by fungicide tiram (1934), and then by compounds from the group of dithiocarbamates (mancozeb) used, among others, to control a dangerous fungal disease – potato blight.

The first insecticides of inorganic origin, which were used up to the 1940s, were strong poisons of high durability, and this is the reason why they currently have only historical meaning. It also seems that issues related to the effects of plant protection products on the environment were beyond the scope of awareness of their users. The example of such dangerous substance was “Paris green” (copper(II)acetoarsenite), used as a green dye for fabric, and used for the first time in 1858 to control Colorado beetle. It was a compound with a burning effect on plants and of high toxicity for humans. It was replaced with lead arsenate, which at high phytotoxicity and accumulation in soil led, among others, to the withering of fruit orchards in California. A lower level of harmfulness for plants was revealed by calcium arsenate, which for many years enjoyed a dominant position in the insecticide market. Fluorosilicates were also applied, although to lesser extent, since because of their low efficiency, they were not competitive against the poisons presented here. Application in the 1960s in Europe of carbon disulphide to fumigate roots of grapevine against an aphid (grape phylloxera) can be regarded as a short episode. It was a very toxic product, explosive and inflammable and quite quickly was replaced by agrotechnical methods, such as grafting grapevines on species resistant to this pest.

At the end of the 19th century, various inorganic compounds, such as sulphuric acid, copper sulphate, iron sulphate, sodium arsenate and petroleum, were used to control weeds. In 1892, Bayer produced the first herbicide of a contact effect - dinitro-ortho-cresol (DNOC), later used also as insecticide and acaricide to destroy wintering forms of pests in orchards. This substance, due to its high toxicity to beneficial entomofauna, was banned in EU countries. Phenolic acids such as 2,4-D, were introduced in 1944 followed by MCPA (1947), which for many years dominated the herbicidal product market. The dates which are remarkable in the history of herbicides include: 1957 – introduction of atrazine by Ciba-Geigy to control weeds in maize (due to its high toxicity to water organisms, hormonal effects and moderate durability in soil, it has been withdrawn from the EU countries as a dangerous compound), 1974 – glyphosate introduced by Monsanto and 1980s - marking the development of low dose sulfonylurea herbicides.

Such rapid development of plant protection chemicals would not have been possible without the introduction of proper equipment. The first companies producing sprayers were established in France (Vermorel) in 1880 and in Germany (Plate and Holder) in 1888. Aerial techniques in plant protection were also developed, an example of which was the use of a plane for the first time to spray fields with lead arsenate in 1921 in the state of Ohio.

The application of pesticides in the period between World Wars was limited in both the area and the range of plant protection products. Preparations were generally not very effective, unselective and primitive and treatments were carried out in a haphazard way, without regard to the real threat to plants. In fruit-farming, winter wash was used to spray trees in the leafless period, and Paris green and arsenates or nicotine decoctions of one's own production were used against insects occurring during the plant vegetation period. Sulphur preparations (today, only of marginal importance) were used against red spiders and fungi causing powdery mildew. Basic fungicides included Bordeaux mixture and lime sulphur.

The real revolution in chemical control of pests took place in 1939, when a Swiss chemist, Miller, who was awarded the Nobel Prize for this discovery in 1948, demonstrated the insecticide properties of DDT (dichlorodiphenyltrichloroethane). It was a "wonder powder", which successfully controlled not only Colorado beetle and other plant pests, but saved also many thousands of lives during World War II by controlling insects transmitting malaria and typhus in humans. While recalling the atmosphere of those years, it should be added that DDT was then treated as a symbol of better future, similar to other inventions from the period of the World War II such as penicillin, radar and the atomic bomb. Over time, it turned out that what appeared to be the greatest advantage of this compound proved to be its drawback. DDT was cheap and easy to synthesize, and the areas over which it was used were free from pests for many months. This product, harmless to humans, birds and mammals, was believed to bring about a real revolution in agriculture by eliminating poisonous arsenic compounds.

In the 1940s, a synthesis of other compounds from the group of polychlorinated hydrocarbons was achieved, including aldrin, dieldrin, endrin, chlordane and chlorinated camphenes. Almost parallel to the research on DDT, in 1943, the Germans, while experimenting with military gases during the war, made a synthesis of the first phosphoroorganic insecticide called parathion**.** In 1950, a synthesis of carbaryl - the first carbamin insecticide - took place in the Ciba-Geigy laboratories, and in 1967, in Great Britain, the first synthetic analogue of plant-derived pyrethrins was produced (as a resmethrine).

Only after a few decades of DDT application did it turn out that it was persistent in the environment and additionally, as a contact poison, it affected various organisms of biocenoses and probably accumulated in food chains, negatively affecting bird and fish fertility. Later research proved that DDT caused calcium management disorders in birds, which led to the reduced thickness of an egg shell and in consequence, to its cracking before hatching. It also accumulates in human fat tissue and has hormonal effects, which has been proved in laboratory research on mice and rats. However, it has never been explicitly confirmed that this compound was a direct cause of any human deaths. DDT is currently included in a group of 12 compounds of so-called Persistent Organic Pollutants (POPs), which are very toxic for animals and humans. These are characterized by their high durability and ability to travel in the environment and to cumulate in fat tissues of living organisms, and are also known for their hormonal effects, as “endocrine disruptors”. It should be also added that one of insecticides from this group, known as toxaphene (which even as late as the 1970s was one of the most commonly applied insecticides in the world) was used under the commercial name of Melipax, which means “peace to bees”.

The campaign against DDT resulted in banning its use in most countries of the world, except for some areas at risk of malaria. In Poland, DDT was withdrawn in 1976, although it should be noted that as a result of its long usage (it was sold under commercial names of: Azotox, Ditox, Tritox), potato bugs, which were the main target of DDT, actually became resistant to it. In the Soviet Union, it was used still for a long time, until an official ban was issued, which took place as late as in 1983. As a consequence, the use of this substance in Uzbekistan alone amounted to 70,000 tons, which led to high contamination with DDT residues of poultry, eggs, powdered milk, soil and water. Another compound from the group of polychlorinated hydrocarbons, BCH, commonly used in Asia, was detected e.g. in food products imported from China to Great Britain.

One of characteristic, unfavourable properties of DDT is its ability to bioaccumulate in subsequent links in the food chain. This can be illustrated by the effects of its application in the vicinity of Lake Michigan in the form of the following residues content in the environment: lake water - 0.000003 mg/kg, small crustaceans - 0.04 mg/kg, small fish - 0.5 mg/kg, predatory fish - 2 mg/kg, predatory birds - 25 mg/kg. This resulted in a strong reduction of the population of predatory birds at the end of the food chain.

Within many years, social awareness developed a negative attitude towards plant protection chemicals, and DDT (at that time a common natural environment contaminant) became a symbol of those substances. According to some sources, its half-life in the environment amounts to 60 years, and if it gets into the atmosphere, it can be moved to areas where it has not yet been applied. This entails a risk of disregarding current threats existing in plant protection, while focusing on non-existing ones or those that do not result from the such properties of plant protection products, like its toxicity to human beings, durability and ability to bioaccumulate. Sometimes, this is reflected in scientific publications, by which they lose credibility and create unfounded fears.

Although modern insecticides are characterized by low usage of active substances per ha, which could suggest their lower threat to the environment, one should realize that doses of 0.01 kg/ha (which occur in practice), can equally effectively, and maybe to a higher degree, affect other biocenose organisms. For the sake of comparison: the oldest insecticides based on DDT were applied in doses of about 3 kg/ha.

The current structure of global usage of insecticides and acaricides, based on their global sales in 2006 according to IRAC (Insecticide Resistance Action

Committee) is the following: phosphoroorganic compounds - 24%, pyrethroids - 18%, neonicotinoids - 18%, carbamates - 11%, polychlorinated compounds -7%, natural products - 6%, benzyl urea compounds - 3%, other compounds controlling insect growth - 2%, acaricides - 6%. What is noticeable in this list is a high share of products of the neurotoxins group (compounds with highly unfavourable ecotoxicological parameters) as compared to environmentally safe III generation insecticides. Phosphoroorganic compounds are one of the oldest broad-spectrum neurotoxins, introduced in the place of DDT that has been withdrawn. They belong to the group of cholinesterase inhibitors, which lead to accumulation of acetylcholine in synapses – a chemical transmitter of nerve impulses. This evokes a constant stimulation of choline nerve fibres of the central and peripheral nervous system, resulting in uncoordinated movement, falling on the back and then death by exhaustion, which can occur after a few minutes. Those compounds are also toxic for humans, which provides another argument for their withdrawal. A similar effect is demonstrated by carbamates. It should be added that this group includes pirimicarb, which is the only neurotoxin considered to be selective towards beneficial insects. A high share in the assortment of insecticides is taken by pyrethroids – compounds of low toxicity to mammals, but of very high toxicity for insects and fish. A lethal effect can occur at the concentration of 500 ml of active substance in w 1 km^3 of water, which is a much lower dosage than in the case of other insecticides. Unlike unstable pyrethrins of plant origin, they are photostable compounds. They cause, just like DDT, disorders in the flow of sodium ions by ion channels in axons. As a result of this uncontrolled, spontaneously repeated electrical discharges occur along neurones in the nervous system of insects. A relatively low price with a rapid lethal effect is the reason for high popularity of those substances on the insecticide market. A disadvantage of those compounds is the easy acquisition of resistance by insects and poor activity in high air temperature. Insecticides blocking chlorine channels, related to receptors of γ-aminobutyric acid (GABA) include fipronil of the phenylpyrazole group, of broad insecticide spectrum. A similar mechanism of operation is characteristic for avermectins, constituting a mixture of antibiotics produced by soil actinomycetes *Streptomyces avermitilis (Actinomycetes).* Neonicotinoids are neurotoxins of growing economic importance, particularly for insects which have became immune to previously applied compounds from other chemical groups. They result in blocking acetylcholine pathways to its receptors located in synapses, while at the same time binding with those receptors as agonists. The result is stimulation of the nervous system and then its paralysis. These are products characterized by stomach and systemic effects, very toxic for insects (which results from a high number of nicotine receptors in their nervous system), but a low level of harmfulness for humans. Some of those products, while applied as seed dressing became a source of controversy as regards their negative effect on bees.

Rare insecticides (described as proecological) include compounds blocking chitin synthesis (acyl ureas), such as diflubenzuron, teflubenzuron, novaluron and juvenoids – inhibiting the metamorphosis of the insect into an adult form (fenoxycarb) and ecdysoides initiating the processes of molting (methoxyfenozide). Acyl ureas affect insect larvae, causing disorders of the molting system, and also affect insect reproduction capacity (larvae do not hatch from eggs). They are non- or low-toxic to beneficial insects, bees and fish. A disadvantage of juvenoids is the need for precise determination of the treatment time (preferably on the egg stage), but they are safe for humans and warm-blooded animals and they are unstable in the environment. The highest selectivity, limited generally to butterfly caterpillars, is demonstrated by methoxyfenozide. A large importance, particularly in the protection of forests and orchards, was given to sex attractants, typically secreted by mature females in order to attract males. These are highly specific compounds; they attract only specific species of insects, are used in very low doses and are subject go rapid degradation. Traditionally, they have been used to signal and record the appearance of pests in order to establish an optimal time for pest control, but their use can be much broader. For example, a well-known method consists in disorienting males while emitting large amounts of pheromones of apple codling moth, which hinders mating. To protect orchards against this pest, there is also applied a very toxic two-ingredient preparation, Appeal 04 PA, in which the addition of pheromone to insecticide ensures its safe and economic application in the amount of a few drops per tree.

Products for biological control of insects, which have been known for many years and applied in practice, include biopreparations, in which a toxic protein produced by soil bacteria *Bacillus thuringiensis,* is the active substance as a poison of natural origin. Unlike typical insecticides of synthetic origin, the death of an insect occurs in this case over a longer time, even after seven days. However, both cases involve chemical and not biological mode of action. It was found that over 150 species of insects, mainly butterfly caterpillars and some dipterans and beetles demonstrate susceptibility to the Bt toxin. It blocks receptors in the cell membrane of the central intestine epithelium in insects, hindering ion transport. Consequently, osmotic balance in alimentary canal is damaged, cells of intestine epithelium break and body dehydration and paralysis occur. Insects die within a few days. Resting spores of bacteria can last even 10 years without the loss of infectious capacities. *B.thuringiensis* bacteria die in an acid reaction of the alimentary canal, which indicates the lack of their harmfulness for humans and warm-blooded animals. They are also harmless for bees. It should be mentioned that introduction of a gene causing synthesis of the above described protein to plants proved that one of the drawbacks of the genetic engineering methods is the acquisition of resistance by insects, just as in case of chemical plant protection.

The need to satisfy the food needs of the growing human population, with the lack of efficient, ecologically safe methods of crop cultivation, means that plant protection chemicals will still play a significant role in the upcoming decades. However, one should take into consideration different priorities in this regard for different countries of the world. An example could be developing countries, which use 50% of global insecticide production and 10% of herbicide production, as compared to the European Union countries, in which those proportions are reversed. The outline of the history of pesticides presented in this paper points out, at the same time, the directions of the development of this area of human activity. Although contemporary plant protection products have more favourable ecotoxicological parameters than their earlier generations, the dominance of pesticides with marginalization of other treatments in the form of integrated plant protection is the source of problems related to their negative effect on the environment. Great hopes are related to biotechnological progress, although in this field no important successes in the reduction of environmental chemization have been achieved. Bearing in mind the requirements of consumers who are looking for chemically uncontaminated food, one have to take into account the need of further changes as regards the assortment of plant protection products, allowing for their more economical and safe application. However, it is very difficult to predict what discoveries will take place in the field of synthesizing new chemical compounds. Generally, it is clear that these should be compounds ensuring efficiency in low doses, of about 0.5 kg/ha, easy in formulation and application, of high effectiveness and favourable exotoxicological parameters and of new, currently unknown mechanisms of operations. Certainly, they will not be cheap, which results from increasing costs of syntheses of new active substances and registration of preparations. According to data from the previous year, one out of about 150,000 chemical compounds subject to examination enters the market, and the registration costs for one plant protection product in the European Union can already reach EUR 200,000,000. The current legal regulations in the EU aim towards further reduction of pesticide usage and limiting the scope of their application. Nevertheless, this will not be fully possible without adherence to these principles on a basic level, *i.e.* by food producers, and without the introduction of new technological solutions allowing for the economic application of pesticides, which currently diverge widely from the required standards.

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