conditions for the development of aerobic microflora and the maintenance of constantly high activity for them. In the complex of agrotechnical and agrochemical measures developed a major role is played by a wide application of organic and microbiological fertilisers and also to growth stimulators and the development of lower and higher plants.

Significant results, obtained from putting into practice a complex of programmes in Japan, USA, Canada, FRG, and other countries in which huge quantities of PCPC have passed into the environment, indicate that mankind cannot now disregard the presence of these poisons in the biosphere and is obliged for many future decades to build up specially new conditions for his poison-free existence and cleaning of the environment. An unsafe medical situation and a multitude of regional ecological outbursts in our country are undoubtedly connected with underestimation of world-wide practice on the route and scale of using chlorine and its compounds and also of attempts to protect man and nature from the technological activity under conditions of enhanced PCPC content in the environment.

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Main directions for reducing the ecological burden when using pesticides

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The influence of human society on the environment began in the period when people moved from gatherings in dense forests to farming and animal husbandry. The process developed particularly intensively in the period of scientific-technical revolution and the creation of various branches of industry. Each branch of modern industry makes its 'contribution' to the action on the environment. Thus combustion of coal and lignite mined at the present time leads to contamination of the environment by powerful carcinogens such as benzopyrene and benzanthracene.[1,2] Combustion of coal alone leads to the discharge of about 3000 tons of mercury into the environment[3] and a significant quantity of sulphur dioxide and other harmful products. It is sufficient to say that in the USA alone about 200 000 000 tons of various chemical compounds pass into the environment each year. Contaminants such as polychlorobiphenyls (used in the electrical industry), polychlorodibenzofurans and polychlorodibenzo-*p*-dioxins formed on combustion of municipal refuse, or when bleaching paper with chlorine and in many other cases are a serious danger. It is possible to form an opinion on the danger of this group of substances only from their acute toxicity for mammals. Thus the LD_{50} of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin for guinea pigs is 0.6–2 μg kg^{-1}, and for monkeys 70 μg kg^{-1}.[4] In addition these compounds possess carcinogenic, teratogenic and immunotoxic actions. The safe concentration of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin in drinking water is considered to be 0.000035 μg $litre^{-1}$.[5] Pesticides as contaminants of the environment amount to less than 1% of total contamination, however since they are physiologically active compounds serious attention is paid to them and there is discussion in print on the expediency of their practical use. In addition it is impossible to obtain high and consistent harvests without the application of pesticides for the protection of plants against vermin, diseases and weeds.[6,7] The application of pesticides is spreading without interruption. In 1986 a total of US$17.4 billion worth were used, in 1987 $20 billion, and according to a forecast their consumption in 1990 will rise to $21 billion.[8]

The consumption of pesticides in various countries in 1987 was as follows (in $ millions): USA 4450, Japan 3450, France 3400, USSR 1075, Brazil 875, Italy 860, FRG 855, Great Britain 760, Canada 545, India 510, Spain 485, Chinese People's Republic 465, Australia 399, Hungary 320, South Korea 280, Denmark 240, Netherlands 210, Argentina 205, Indonesia 170 and Mexico 155. The consumption of pesticides in 1987 according to preparation types was (in $ millions): herbicides 8600, insecticides 6100, fungicides 4100 and others 1200. It should be noted that the data given cover only 20 countries, the largest consumers of pesticides.[8]

The influence of pesticides and other xenobiotics depends on the following main properties: persistence, acute and chronic toxicity for various forms of living organisms, decomposability under the action of various forms of living organisms (biodecomposition) and the presence of various negative effects from small doses of preparation over an extended time. Pesticides are subdivided into six

groups according to persistence: 1) preparations with a retention time in the environment of more than 18 months, preparations with a retention time of 2) 18 months, 3) 12 months, 4) 6 months, 5) 3 months and 6) less than 3 months. It is quite evident that depending on climatic conditions the retention time of any xenobiotic in the environment may vary within fairly wide limits. However it is possible to use the following formula to compare individual preparations for persistence and overall ecological burden on the environment:

$$EB = \frac{C}{LD_{50}} P,$$

where EB is the ecological burden per hectare, C the standard consumption of the preparation per hectare in g, P the persistence of the preparation in weeks (half life) and LD_{50} is the standard acute toxicity in mg kg^{-1}.[9] Finally, the formula shown does not give absolute values but enables comparison of the relative danger from one preparation to another.

Table 1. Persistence, acute toxicity and standard consumption of pesticides of various generations.

Pesticide generation	Persistence group	LD_{50}, mg kg^{-1}	Standard consumption, kg $hectare^{-1}$
Insecticides			
First generation:			
arsenic compounds	1	1.8–5	4–10
Second generation:			
organochlorine	1–2	25–1000	0.1–2
organophosphorus	5–6	1–3000	0.5–5
carbamates	5–6	25–1000	0.5–2
Third generation:			
pyrethroids	5–6	40–2000	0.006–0.1
hormonal	5–6	1000–2000	0.05–0.3
Fungicides			
First generation	1–3	5–450	5–9
Second generation (disinfectants)	5–6	18–200	0.003–0.2
Third generation (dithiocarbamates)	5–6	400–6000	1.8–3
Fourth generation (azoles)	5–6	400–4000	0.025–0.15
Herbicides for monocotyledonous weeds			
First generation (TCAN, Dalapon)	4–5	3000–4000	4–20
Second generation (thiocarbamates)	5–6	400–1400	1–2
Third generation (hydroquinone derivatives)	5–6	800–3000	0.25–1
Herbicides for dicotyledonous weeds			
First generation:			
dinitrophenols	5	40–100	2–4
ammonium sulphate, chlorates	4–5	100–500	200–600
Second generation (aryloxyalkanecarboxylic acids, benzoic acid derivatives)	2–4	300–1000	0.2–2
Third generation (sulphonylureas)	1–6	1000–5000	0.01–0.05

It should be noted that in the last decade pesticides have undergone profound changes both in persistence and in ecological burden on the environment and in danger to animals and man. Data are shown in Table 1 on some properties of pesticides of various generations. As is evident from Table 1 a sharp change has occurred in the persistence, toxicity and standard consumption per hectare of the preparations under consideration. For example the standard consumption of insecticides has been reduced from several kilograms to several grams per hectare, the acute toxicity has also changed. Preparations may be selected with different duration of action and the same toxicity for mammals. Earlier compounds, chiefly of arsenic, were used which had a practically absolute persistence but at the present time there are preparations which are decomposed into the simplest substances during one or two days, weeks or months. Such preparations may not damage the environment.

There is a completely analogous picture for fungicides the standard consumption of which is up to 25–100 g $hectare^{-1}$. At such standards of consumption it is difficult to visualise contamination of the environment, since two tons of soil will carry 2.5–10 mg preparation. Results on the design of new herbicides are particularly prominent both for control of monocotyledonous and dicotyledonous weeds.

Regarding persistence it is also possible to select herbicides the rate of decomposition of which does not exceed one vegetation cycle.

It should also be noted that fairly weakly toxic preparations may be selected according to their mammalian toxicity, in many cases not exceeding the acute toxicity of sodium chloride. It is pertinent here to recall the hypothesis of Paracelsus, that all substances are poisonous but only the dose makes them a poison. This hypothesis is also true for establishing maximum tolerated levels (MTL) for such effects as teratogenic and carcinogenic action. For example on feeding animals with food containing more than 120 g kg^{-1} ethylenethiourea, the appearance of malignant tumours is observed while at a lower content of this substance in food no carcinogenic action was recorded. Furthermore it is necessary to study the possible remote consequences of the action of small doses of preparations over an extended time in certain animal species and in three generations of experimental animal. Adequate guarantees of the safety of a preparation will emerge in such a study.

An important problem in the study of new preparations is their biodegradation by various species. With this aim the metabolism of pesticides has been studied in mammals, plants and microorganisms with isolation and identification of all the pesticide decomposition products and also with determination of the rate of metabolism and the dynamics of residues at harvest. Determination of the dynamics of decomposition of pesticides in plants enabled establishment of the expected time after treatment necessary to obtain products free of pesticide. In many countries the expected time is the chief criterion for the quality of products treated with pesticides (in addition to analytical determination of residues of them at harvest). Finally the expected time, which is determined for each region separately, may not be the same under different climatic conditions and in different cultures. The expected time is linked to a significant extent with temperature, residues and the metabolic rate in a given culture. For example chlorosulphone metabolises rapidly in wheat and is practically not decomposed at all in sugar beet.

Prior to permitting a new preparation for practical use in agriculture it is carefully studied in all the aspects enumerated above including the mutagenic, carcinogenic action and the teratogenic effect in animals. However data obtained in one animal species may not always be transferable to another animal species or man. Consequently a 'safety margin' is taken which in the majority of cases is two orders of magnitude less than the safe level for animals.

Pesticides intended for the treatment of animals and their food are studied in a given species of animal. Not only is their content determined in animal husbandry products going into human food but also the dynamics of their elimination from animals and the character and content of the metabolic products. Such a study guarantees to a fair degree the safety of using animal husbandry products in human food. It is noted that preparations which give residues in animal husbandry products, are not used at the present time in the majority of countries. However it is necessary to note that after use fairly significant quantities of DDT, toxafen and other similar substances were retained in the environment, hence residues of the substances indicated are frequently found in water although in insignificant quantities.[10] It is noted that significant quantities of polychlorobiphenyls are found in many living organisms as is seen from Table 2.

Table 2. Content of polychlorobiphenyls in various forms of animal.

Organism	Year	PCB content mg kg^{-1}*	Region
Pike	1980	2.4	Baltic
Guillemot	1981	100	Sweden
Cormorant	1975	130	Sweden
Eider	1980	2.6	Spitzbergen
Osprey, eggs	1978	200	North Sweden
Marsh harrier, eggs	1977	150	North Sweden
White tailed eagle	1982	340	Lapland
Grey seal	1976–1978	38	Baltic
Ringed seal	1981	85	—
Greenland seal	1982	4.5	—
Caspian seal	1977	1.5	Caspian

*Calculated in lipids.

As is known polychlorobiphenyls are not used as pesticides but are extremely stable compounds being metabolised slowly by various living organisms. Even more stable is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin which may be retained in Californian soil for more than 14 years.

It is noted that extremely poisonous compounds, products of the metabolism of phytopathogenic fungi, such as mycotoxins, may accumulate in the environment. The toxicity of some of them is given in Table 3. The use of pesticides enables elimination of mycotoxins which possess carcinogenic and mutagenic action as well as high toxicity.

Analysis of grain cereals for nivalenol content (500 samples from 19 countries) showed that mycotoxins may be contained in grain in extremely significant quantities.[11] Results are shown in Table 4 on the determination of nivalenol in several grain crops from 19 countries. It shows that the nivalenol content of same samples reached fractions of one percent. Fungi of the fusarium, verticillium and some other genera are producers of many toxins.

In addition to the toxins produced by microorganisms there are a large number of poisonous plants in nature by which people used to be poisoned with lethal outcome. In Central Asia over 30 years there was a large number of poisonings by trichodesma seeds which contaminated wheat and entered flour, as a result of which many cases of poisoning were recorded. After the application of herbicides of the aryloxyalkanecarboxylic acid type this weed was successfully eliminated and poisoning of people ceased. Toxicities for mice of certain peptides isolated from plants are given in Table 5.[12] As is seen such peptides are extremely toxic and are close in potency to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, which is the most poisonous xenobiotic.

Table 3. Acute toxicity of some mycotoxins in rats.

Mycotoxin	LD_{50}, mg kg^{-1}
Aflatoxin B_1	7.2
Toxin T	3.6
Nivalenol	7.4
Fusarenone X	4.4
Maloformin	4.0
Strychnine (for comparison)	7.5

Table 4. Content of the mycotoxin nivalenol in various cultures.

Culture	Nivalenol content, mg kg^{-1}
Wheat	127
Barley	101
Maize	766
Rye	47
Oats	438
Rice	22
Sorghum	90

Table 5. Acute toxicity of some peptides of vegetable origin.

Name	Plant	LD_{50}, mg kg^{-1}
Abrin	*Abrus precatorius*	0.6
Viscotoxin	*Viscum album*	2.4
Volkensine	*Adenia volkensii*	1.4
Modecin	*Adenia degitata*	2.1
Ricin	*Ricinuscommunis*	2.6

The 17-year experiment of Polish investigators on the influence of pesticides in crop rotation on the environment is of interest.[13] It was carried out from 1963 to 1980 in an area of more than 500 hectares. In all of this period 11 846.3 kg pesticides were applied to the area mentioned. This included 804.2 kg DDT, 376.26 kg Lindane, 170.28 kg Methoxychlor, 476.626 kg organophosphorus and carbamate insecticides, 697.975 kg fungicides (including 9.02 kg mercury compounds) and 9315.302 kg herbicides. All products grown on the area mentioned were analysed each year as well as the wild animals, birds, water and soil. As a result of the work the

authors concluded that contamination of plants by pesticides, Lindane, DDT, or organophosphorus compounds was not observed. They were not detected in the parts of plants near the ground nor in roots. It is particularly interesting that they were not detected in potato tubers or in sugar beet in spite of their presence in the soil. The best test object for determining soil contamination by organochlorine preparations is the earthworm, in which bioconcentration of DDT and Lindane occurs, and is linked with their constant living in soil and feeding specifically on organic residues. Ground beetles and field mice are also capable of accumulating organochlorine preparations and carbamates but do not accumulate organophosphorus compounds.

The observations of the Polish investigators correlate to a definite extent with results of the work of scientists of other countries, including the Soviet Union.

The dynamics of growth of the numbers of wild animals and birds are of interest. In Hungary in 1967 roe deer, boar, deer, grey partridges, pheasants and hares were recorded at 107.8, 12.2, 21.8, 588, 889.0 and 101.76 thousands respectively at a pesticide consumption of less than 3 kg hectare^{-1}. In 1974 when the consumption of pesticides per hectare of seeding and planting land had grown to 4.6 kg the numbers of animals indicated above increased to 173.0 17.0, 38.0, 860.0, 2360.0 and 1100.0 thousands respectively.[14] A similar picture was observed in North Rhine Westphalia.

The influence of pesticides on aquatic flora and fauna has great significance and in this connection their toxicity for water organisms, including various fish species, has been studied in an extremely detailed manner. It was established that organochlorine compounds are capable of accumulating in fish, from which they are eliminated comparatively slowly and as a result they may pass with the fish into the human food chain. However, the use of such a type of compound has either been sharply reduced or stopped completely in the majority of countries, including the Soviet Union. Organophosphorus pesticides themselves do not as a rule accumulate in fish and are rapidly eliminated. For example Carbofos is eliminated from fish in one day and other phosphorus pesticides in a week.

It is necessary to record that the use of insecticides in agriculture may be reduced by 30–50% by using sex pheromones for determining numbers of the most dangerous pests and determining thresholds for their noxiousness. Pheromones are ecologically clean and may not damage the environment or useful insects. It is expedient to use insect pheromones as widely as possible. Pheromones may replace insecticides to a significant extent in the disorientation of insects.

Cutting down the consumption of fungicides may occur only through the removal of stable sorts of plants, which however lose their resistance to a given form of disease after 2–3 years. In this connection it is doubtful whether it will be possible to give up fungicides in the next decade. There is no reasonable alternative to herbicides. In addition, in the majority of cases residues of herbicides are not found in the harvest. However in all cases it is most expedient to use a combined system of plant protection with intensive farming technologies. An integrated system of plant protection when considering harm thresholds and a well tuned monitoring of harmful organisms helps appreciably to reduce the ecological burden arising from the use of pesticides.

It is necessary to set up a state plant protection service of the type of the veterinary service which will secure correct and intelligent use of pesticides and the observance of a standard plant health situation. Special self-supporting teams must be set up for plant protection for tenants, which should use pesticides in a skilled manner and guarantee purity of the resulting products.

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