Balancing Chemical and Non-chemical Methods to Manage Plant Diseases, Pests and Weeds

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The late president of the Club of Rome, AURELIO PECCEI, in his book entitled "One Hundred Pages for the Future" /1981/ expressed the opinion that temporary advantages stemming from the exploitation of natural resources or natural powers involve high prices to be paid in the not-too-far future because in many cases the uncontrolled technology turns out to be harmful to our natural environment.

This is also true in many instances for the advantages secured by technologies in plant protection. As a rule, chemical control measures pollute the natural environment. The number of pesticides as well as the number of active ingredients has increased during the past decades /Fig. 1/. Therefore, there is a world-wide need for new, non-chemical and environmentally safe control measures in agriculture, instead of chemical methods in disease, weed and pest management. This need is stressed all over the world, although the toxicity of pesticides applied in agriculture during the past forty years is less than that of the early ones. According to optimistic extrapolations, at the beginning of the next century the toxicity of pesticides will be greatly reduced /Fig. 2/.

During the past twenty years many mistakes have been made with manufacturing and applying pesticides against plant diseases, weeds and insect pests, and a few disasters have also been recorded. I refer to the non-target effects of DDT and 2,4,5-T, which turned out to be harmful even for humans. The tragic event in India in 1985 with methylisocyanate, a precursor of an insecticide, as well as the very strong correlation in a recent Canadian study between Parkinson's disease incidence and level of herbicide use /BARBEAU, A., 8th Int. Symp. Parkinson's Disease. New York, June 9-12, 1985*/ called attention to the importance of health and environmental aspects of plant protection control measures /cf. LEWIN, 1985; SNYDER and D'AMATO, 1985/. In the latter case herbicides containing paraquat or cyperquat and some structurally similar defoliating agents have been implicated as causes of Parkinson's disease. Another adverse effect stems from the regular use of pesticides during rice-cultivation. The residues of pesticides in the soil might inhibit the growth of the nitrogen-fixing and therefore useful cyanobacteria. These bacteria could be regarded as natural fertilizers /cf. PADHY, 1985/.

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* Since the presentation of this paper several reports of such vital interest have been published that the author deems it necessary to include them among the references.

The detection and evaluation of the non-target effects of pesticides are rather complicated. In many instances only incidental experiences call our attention to the non-target effects of several compounds. One of this type of undesigned experiments has been made by OROS et al. /1983/. Most probably there is a natural antagonism in the soil between the nitrogen fixing <u>Rhizobium japonicum</u> and <u>Diaporthe phaseolorum</u>. However, the balance be-

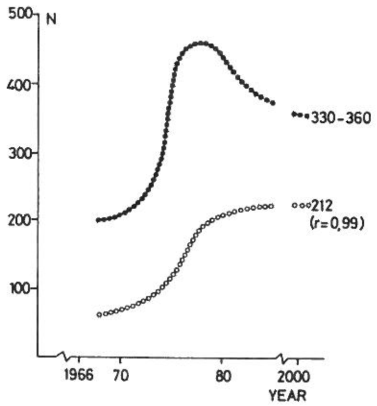

Fig. 1
The number of pesticides used in Hungary in different years. Upper curve: commercial products. Lower curve: active ingredients

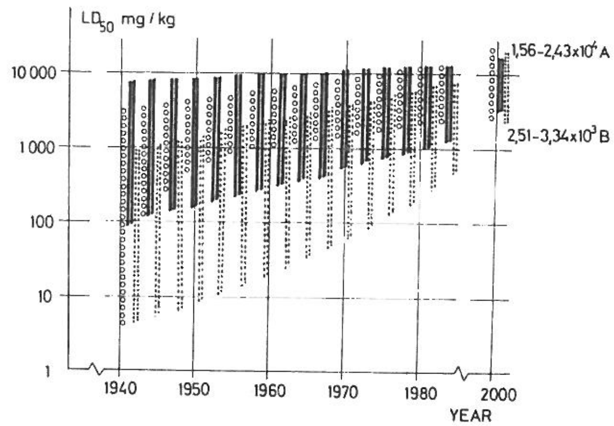

Fig. 2
Toxicity of pesticides for warm-blooded animals at the time of introduction during the past four decades. Double solid line: fungicides, Double dotted line: insecticides. Line composed of little circles: herbicides. A: expected smallest main toxicity in the year 2000. B: expected highest main toxicity in the year 2000. The data for LD_{50} mgL^{-1} for rats are taken from the Pesticide Manual

tween the microorganisms will be disturbed if an effective fungicide /Tilt/ is present in the medium even in a sublethal concentration. Neither microorganisms will be inhibited because of the low level of this fungicide, but the antagonistic effect of Rhizobium to the pathogenic Diaporthe will be eliminated and the pathogen will overgrow Rhizobium, at least in the laboratory tests /Fig. 3/.

Fig. 3
Antagonism between Rhizobium japonicum and Diaporthe phaseolorum as influenced by the fungicide proconazole /Tilt/. Upper left: Rhizobium and Diaporthe in the presence of 0.1 mgL^{-1} proconazole. Upper right: Antagonism between Rhizobium and Diaporthe in the absence of proconazole. Lower right: Diaporthe in the absence of proconazole

It is obvious that neither the public nor governments are satisfied with chemical control measures after so many bad accidents and dangerous impacts of different compounds on the environment and public health. Environmental protection has become a national priority in many countries. Public hope, however, usually exaggerates the new biological and other non-chemical control measures. Several concepts and even slogans have been developed during the past twenty years: "Environmentally safe, selective, biological, non-chemical or integrated plant protection." The latter expression designates the necessity of the integration of biological, chemical and agrotechnical measures against diseases, pest and weeds to diminish the quantity of chemical agents that pollute our environment.

In Hungary today 11 kg pesticides are applied per hectare on the arable land. The active ingredients constitute roughly the half of that quantity, 5.5 kg/ha. This amounts to 70,000 tons of pesticides for the six million hectares of agricultural land. The proportion of different pesticides used in Hungary is as follows:

herbicides - 60%; fungicides - 30%; insecticides - 10%.

It can be seen that the most common chemical compounds belong to the herbicides. Although I do not believe we can expect a general breakthrough in substituting chemical pesticides with non-chemical control measures, still it is important to suppress pesticide use in as many fields as possible in controlling diseases, pests and weeds.

Weed control

At present, neither in Hungary, nor in many other countries exists such a biological control measure that would be applicable in crop production against weeds. However, intensive research is going on to identify and to make use of the natural diseases and pests of harmful weeds. This endeavour has been successful in the case of weeds living in natural waters and ponds. As regards the weeds of crop plants, the economically valuable results are rather limited. One impressive case was mentioned by SUGAWARA et al. /1985/. He isolated the toxin of a pathogenic fungus, Helminthosporium cynodontis, that infects one of the most ubiquitous weeds, Bermuda grass /Cynodon dactylon/. The toxin is a very specific weed killer, indeed the first selective toxin against a weed. It is harmful specifically to the unwanted weed species and represents a "natural" compound.

Crop production in Hungary still relies on regular chemical weed killers. A breakthrough cannot be expected within 1-2 decades. This makes it understandable that in plant protection chemical control measures cannot be replaced with biological or other non-chemical methods in the near future. This fact simply does not permit extreme optimism in this field.

A more realistic approach would be aiming at the decreasing of the quantity of herbicides to be applied in intensive crop production. At least three results seem worth mentioning. According to the results of experiments conducted in our Institute in cooperation with Nattermann Co. /Köln/, phospholipid-containing adjuvants, derived from soybean or sunflower seeds, in a mixture with herbicides can reduce the effective concentration of postemergent herbicides. The adjuvants increase the penetration of the weed killer compounds into the different organs of weeds thereby reducing the concentrations of poisonous herbicides. Another approach is to mix glyphosate herbicides with NH_4NO_3-containing fertilizer and spraying the plants with that mixture in the field /GIMESI, 1983/. The mechanism of this phenomenon is unknown at present but the usefulness of the procedure is obvious. The third method for the reduction of herbicides seems to be revolutionary. The DuPont Co. released a new sulfonyl-urea type herbicide which, in extremely low concentration, can kill weeds in cereal crops. Only a few grams per hectare are necessary for successful weed killing. It would seem that the extremely low quantity of the herbicide almost nullifies environmental pollution. The toxicity of the new herbicide for animals and men is not higher than that of regular herbicides, thus the safety of the new compound seems assured. The Organic Chemistry and Weed Research Departments in our Institute have a promising program with their own low-concentration--herbicide in wheat. The above-mentioned approaches are the only realistic methods, at least in Hungary, applicable in crop production for reducing herbicide pollution in agriculture and horticulture.

Plant diseases

The control measures in suppressing crop diseases caused by infectious microorganisms include several biological /non-chemical/ methods and integrated managements.

The research on controlling plant diseases with biological methods has a long history /BAKER and COOK, 1974/. Still, results and discoveries were cnly occasionally applied in agricultural practice. From the 1930s scientists have realized that a few soil fungi /e.g. Trichoderma spp./ produce antibiotics inhibiting pathogenic soil fungi which are the causative agents of damping off disease and root diseases /WEIDLING, 1932; DENNIS and WEBSTER, 1971/. It has turned out that several species of Trichoderma are antagonistic to fungi such as Pythium, Rhizoctonia and Fusarium. Researchers have shown that propagules of Trichoderma introduced into soil produce antibiotic substances, and these applied as seed coat, can control important plant diseases. Indeed, the early experiments carried out in the 1930s produced the very first evidences for using an antibiotic in controlling an infectious disease. Recently, one can experience a renaissance of the Trichoderma-research because of the pressure of environmentalists. Scientific journals publish successful results from month to month on controlling plant diseases by this antagonistic fungus or by its antibiotic. The Hungarian endeavours are also promising /VAJNA, 1984/.

Another biological control measure, already used in practice, is effective against a plant tumor caused by Agrobacterium tumefaciens. Australian scientists discovered that the tumor-causing bacterium A. tumefaciens can be antagonized successfully by another soil bacterium, A. radiobacter /KERR, 1980/. The suppressive agent, e.g. the bacteriocin, produced by A. radiobacter is also able to antagonize the oncogenic A. tumefaciens. However, the strains of the oncogenic bacterium that are sensitive to the effect of the bacteriocin are only those that induce tumors in stone fruits. The strains oncogenic to grapewine and decidious trees are insensitive to A. radiobacter or its bacteriocin. Recently research programs have been launched in several laboratories intending to find A. radiobacter strains that are also specialized to grapes and other fruit trees. In our Institute S. SÜLE worked out a new biological method that applies bacteriocins of A. radiobacter against the tumorous disease of stone fruits /SÜLE, 1982/.

Infectious wild diseases of plants /including fusarial infections/ are hard to control either by chemical or non-chemical measures. An integrated method, however, worked out in our Institute, has proved to be almost completely successful /SARHAN and KIRÁLY, 1981; SARHAN et al., 1982/. We have found that juvenile plant tissues are resistant to symptoms caused by necrotrophic pathogens /KIRÁLY, 1976; BARNA et al., 1985/. It is possible to increase plant juvenility in several ways. The most suitable method is to supply abundant nutrients, first of all nitrogen, in the soil or in the nutrient solution. Particularly NO_3-nitrogen causes juvenility in several crop plants. For example, tomato reacts sensitively to N in the nutrient solution. Leaves become green, the chlorophyll content increases, and the cytokinin hormone level rises in the tissues. The composition of membranes also changes because the phospholipid:sterol ratio increases /BARNA et al., 1985/. A high phospholipid:sterol ratio is characteristic of plants that are resistant to different stresses. All in all, the high NO_3-nitrogen supply suppresses the need for fungicides in controlling fusarial wilt diseases. In sustainable agriculture the two measures are integrated: high nitrogen supply is combined with reduced quantity of fungicides. It must be stressed, however, that juvenile plant tissues are resistant only to necrotrophic pathogens but not to infections caused by biotrophic pathogens. Unfortunately, juvenile plants are particularly suitable hosts for biotrophic fungi and viruses.

Recently, it was shown that fungicides at sublethal dosages may affect disease development importantly. By testing triadimefon against powdery mildew of wheat, it was determined that disease efficiency and sporulation capacity were reduced greatly by amounts less than one-one hundredth of the recommended dosages /SCHEIN et al., 1984/. Fungicides used in this way might enable management of some plant diseases at less cost and with reduced risk of non-target effects and causing rapid selection of fungicide tolerant populations.

Insect pests

In controlling insect pests several biological and selective control measures are available to reduce the use of insecticides.

The most important prerequisite is an effective forecast system. By successfully forecasting the mass occurrence of insects, a twofold effect can be achieved: One can reduce the number of chemical sprayings and other treatments, and also preserve the natural enemies of insect pests. Thus, environmental pollution will be minimized. Furthermore, if the timing of chemical control is appropriate, it will not damage populations of insect parasites and predators, thereby preserving the natural balance between insects and their enemies. By forecasting the natural enemies of insects, the non-target effect of insecticides will also be diminished. During the past few years a joint project has been developed by the Plant Protection and Agrochemical Center of the Hungarian Ministry of Agriculture and Food and our Institute to establish a forecast system in apple orchards in order to preserve the natural enemies of apple insects, such as predatory mites, coccinellids, lacewings and the larvae of syrphids, by the precise timing of chemical sprayings - or even omitting them altogether - during the peak occurrence of those enemies.

By the application of color and other traps in orchards one can effectively reduce the insect population /e.g. cherry fruit fly/ without chemical control. It has been concluded by Hungarian entomologists that it is possible to produce cherries without any chemical control measures if color traps are applied in the orchards. However, there is a regular 5% infestation in the fruits caused by the cherry fruit fly. This seems to be satisfactory for the environmentalists, but not for the consumers.

Traps are sometimes combined with attractants and insect-behaviour-modifying pheromones. In Hungary traps are mainly used for registering the changes in insect populations, providing thereby a better basis for a reliable forecast system.

The selective chemical control of insects comprises insect hormone analogues, pheromones and specific attractants or repellents that are not harmful to other living organisms including people. The highly specific compounds interfere only with several specific insect functions or with the synthesis of compounds, such as chitin or juvenile hormones, that are formed only or mainly in the insect pests. These very selective insecticides are environmentally safe and without harmful impact on human health. Regarding the future of selective control measures, experts are optimistic in spite of the fact that at present this technique is only in an experimental stage /cf. MATOLCSY et al., 1981; COHEN and CASIDA, 1983; KYDONIEUS and BEROZA, 1982; SZENTESI and JERMY, 1985/. However, pheromones are already used in practice for monitoring and trapping boll weevil in cotton farms where insecticides are applied only when needed to hold down the population. Also in forests, where the use of pesticides is not practical, trapping, the use of attractants and repellents as well as biological control measures seem promising.

The genuine biological control of insects has a long history. Hyperparasites /Trichogramma/, predators and insect disease-causing bacteria such as Bacillus thuringiensis/ or fungi /Beauveria bassiana/ may play a role in it. In Hungary a few pheromones, the Bacillus thuringiensis and hyperparasites as well as predators in the greenhouse are applied in plant protection practice. The above-mentioned bacterium is effective against insect pests on forest trees /tussock moth/ as well as against noctuids and arctiid moths damaging several plant species. The parasitic micro wasps /Trichogramma/ lay their eggs into the eggs of several insect pests, thereby suppressing the number of harmful insects. One of the most promising fields of application of Trichogramma would be the biological control of the European corn borer. However, several technical requirements cannot be met at present in relation to the mass production and distribution of parasitic wasps /HUFFAKER, 1971/.

Breeding for resistance and producing disease resistant cultivars

Breeding and producing disease and pest-resistant crop cultivars seem to be one of the most effective non-chemical control measures. So far moderate but important success has been achieved in this field. Basically this is not a genuine control measure, but in fact it is the most effective "biological control" of diseases and pests of crop plants. It would seem that in the near future several crop plant cultivars will be released that are also resistant or tolerant to herbicides. Particularly the application of new biotechnological methods permit this assumption.

The conventional breeding methods, such as selection, sexual hybridization and the induction of mutations were used in the past. Recently, the new somatic genetics, the recombinant DNA technique, and several biotechnological procedures make it possible to create and select fantastic new types of plant species /WATSON et al., 1983; MALIGA, 1984/.

The vegetative selection methods or the in-vitro selection techniques permit the selection of protoplasts, single cells or tissues against pathogenic toxins, herbicides etc. /cf. Mutation Breeding for Disease Resistance Using In-vitro Culture Techniques. IAEA, Vienna, 1985. IAEA-TECDOC-342/. The main problem is the regeneration of the resistant protoplasts, cells or tissues into whole plants. The present possibilities are rather limited. Another method of breeding for disease resistance is the somatic hybridization of protoplasts or cells, transmitting thereby genes for resistance from one species to another. This method seems particularly useful in those cases when the two species to be crossed cannot be hybridized by sexual crossings. Regeneration of the whole plant is the main problem also in this case.

It is known from recent literature on plant breeding that a significant proportion of the tissue culture regenerates may have altered characteristics with respect to resistance to diseases or insect pests. This type of genetic variability has been termed somaclonal variation. It develops in the absence of any selective pressure, and could be extremely useful in creating disease resistant cultivars /LARKIN and SCOWCROFT, 1981/.

The recombinant DNA technique intends to introduce new genes into crop plants by the application of several vectors, such as Agrobacterium tumefaciens, A. rhizogenes or some DNA plant viruses.

Recently it was found that direct gene transfer to plant protoplasts is not a hopeless procedure. This eliminates the need to introduce the desired foreign gene into Agrobacterium or other vectors before insertion into the plant. Protoplasts take up DNA which is normally unable to penetrate the cell wall barrier, only with very low efficiency. According to a new method, plant protoplasts are treated with a high voltage electric pulse /electroporation/ which alters their membranes, allowing a direct introduction of the foreign gene into plant protoplast. The procedure was combined with heat shock and other factors to achieve high transformation efficiencies /SHILLITO et al., 1985; FROMM et al., 1986/. The transformants have to be regenerated into whole plants also in this case. Another important requirement is to obtain particular genes for resistance in pure form and in useful amounts before devising ways of inserting these genes into crop plants so that they can function. Research in this field is only at the very beginning.

One may conclude that the new biotechnological procedures are of great promise for breeding disease-, insect- and herbicide resistant plants, reducing or altogether eliminating the need for chemical control measures.

In summary, I have tried to outline the latest chemical and non-chemical possibilities of plant protection that are not endangering our health and environment. Our present aim is to establish an acceptable balance between chemical and non-chemical control measures. Although no breakthrough may be expected in this field for twenty years or so, we can count on a slow and rational suppression of chemical control measures, and on the increased efficiency of environmental protection.

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