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Use, Research and Development of Pesticides in Relation to Sustainable Agriculture in Japan

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Abstract

To promote sustainable agriculture in Japan, the use of, and research and development strategy for, synthetic pesticides were studied. The following aspects were investigated: (1) history of pesticide use in Japan, (2) benefits and risks of pesticide use, (3) changes of pesticide properties, and (4) effects of pesticides on ecosystems. Based on the results of the investigation, optimum method of pesticide use and research and development strategy to promote sustainable agriculture were proposed.

Discipline: Agricultural chemicals
Additional key words: benefits and risks, toxicity, behavior in environment

Introduction

Every activity entails both advantages and disadvantages. In the case of synthetic pesticides, as the environmental problems attracted a great deal of attention, people were concerned only with the disadvantages. It is obvious that pesticides have played an important role in stabilizing food supply, maintaining product quality, especially appearance, and enhancing agricultural productivity. However, presently Japanese consumers are concerned about the safety of farm products and effects of pesticides on the environment. Some Japanese farmers have noticed such a situation and started to cultivate farm products without using agrochemicals or by using smaller amounts. The number of such farmers is increasing year by year. In the second half of the 1980s, the concepts of LISA and Sustainable Agriculture were introduced from the USA and EC, respectively. At the same time, global environmental problems arose, such as greenhouse effect and destruction of the ozone layer. Under such conditions, Japan new agricultural policy was enacted in June 1992. In this policy, Japanese agriculture aims at promoting sustainable agriculture. To achieve this objective, reduction of the adverse impact on the environment is included in the policy. Although a low input of agrochemicals is recommended, we do not know how much the rate of pesticides applied can be reduced while maintaining productivity under the agro-environmental conditions prevailing in Japan.

The Japanese climate is humid, with a high temperature and abundant rainfall, as it belongs to the Asia monsoon climate. Japanese agriculture is very intensive. Under such conditions, crops, vegetables and fruits are prone to damage by diseases, insect pests and weeds. Japanese fields consist of paddy fields and upland fields. Paddy fields are covered with flooded water. About 50% of upland fields are covered with volcanic ash soil which contains more than 3% of organic matter. These 2 factors affect significantly the behavior and side-effects of pesticides in the Japanese environment.

Considering the Japanese agro-environment and social needs, researchers in the field of pesticides and environment in Japan will have to promote a more effective pesticide use and determine the reduction rate of pesticide use in the near future. The objectives of this study are to propose a method of pesticide use and a research and development strategy for the promotion of environmental conservation and sustainable agriculture.

History of pesticide use in Japan

Fig. 1 shows the annual changes of pesticide production from 1960 to 1992 in Japan[5]. From 1960 to 1970, the production rapidly increased. From

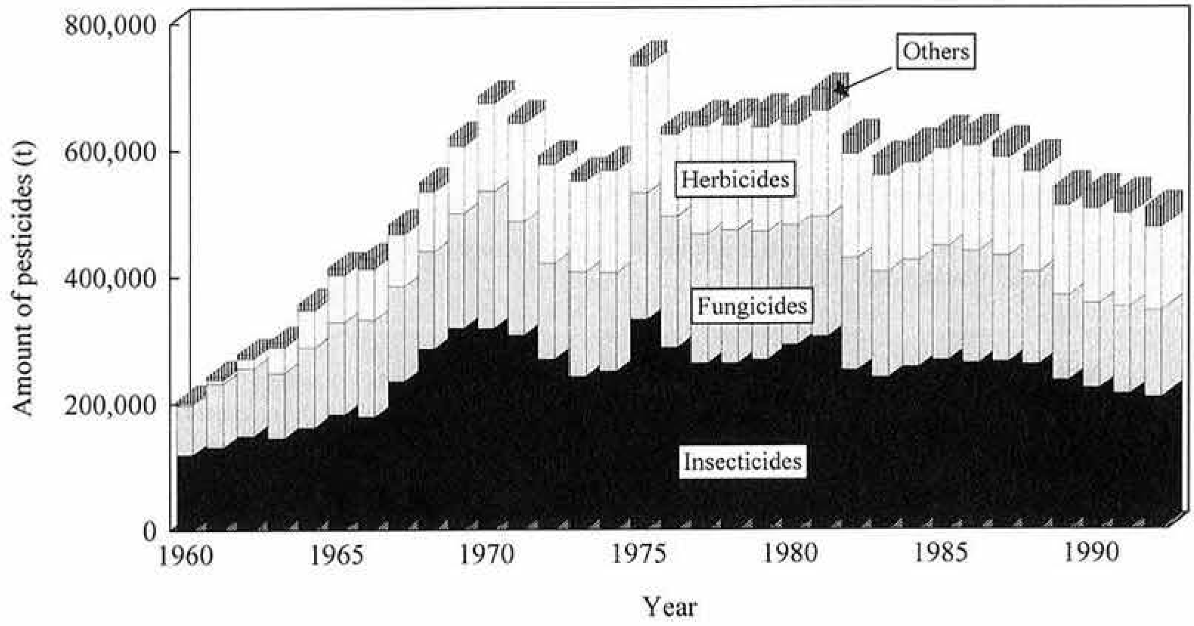

Fig. 1. Annual changes in pesticide production in Japan

1970 to 1985, the production remained relatively constant at about 600,000 t per year. Thereafter, the production gradually decreased and in 1992 the amount was about 500,000 t per year. Most of the pesticides produced in Japan have been used in Japan. The production of active ingredients in herbicides from 1968 to 1992 in Japan was also investigated. From 1968 to 1973 the amount increased, but thereafter the amount gradually decreased[5]. These investigations indicate that the amount of released pesticides and active ingredients into the environment is gradually decreasing in Japan.

In the USA pesticide use rapidly increased from 1965 to 1978. However, thereafter, the amount remained relatively constant and in 1985 it stood at about 400,000 t per year[12]. The amount used was 10% less than that in Japan in 1992, indicating that pesticide use per ha of field in Japan is about 40 times higher than that in the USA. These results suggest that sound agro-productivity could be maintained in Japan if pesticide use were to be reduced as observed in the USA.

Benefits and risks of pesticide use

1) Benefits

Fig. 2 shows the decrease in yield associated with the damage caused by diseases and insect pests without pesticide use in Japan. When pesticides were not used, yield of agro-products decreased by about 35%, suggesting that field productivity increased by

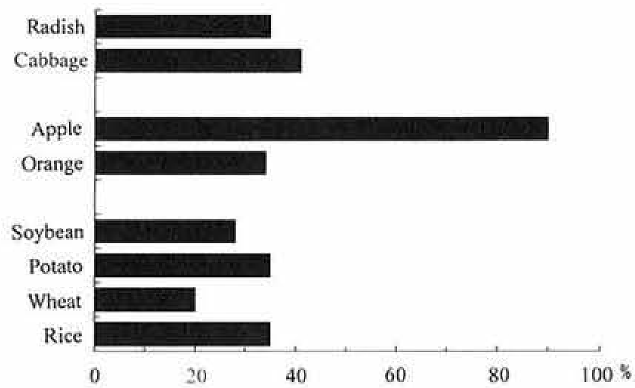

Fig. 2. Decrease in crop production due to damage from disease and insect pests in Japan without pesticide use

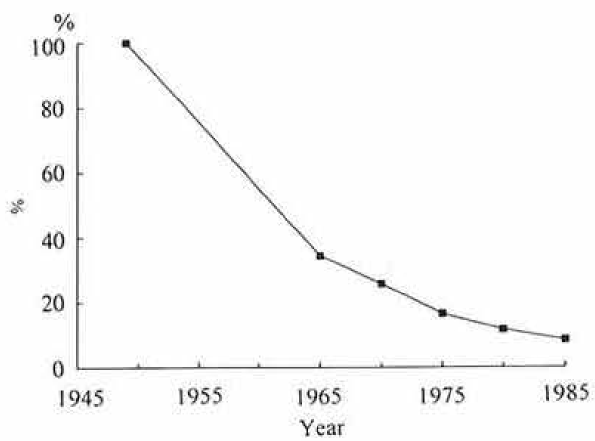

Fig. 3. Decrease in manpower for rice production in Japan due to herbicide use

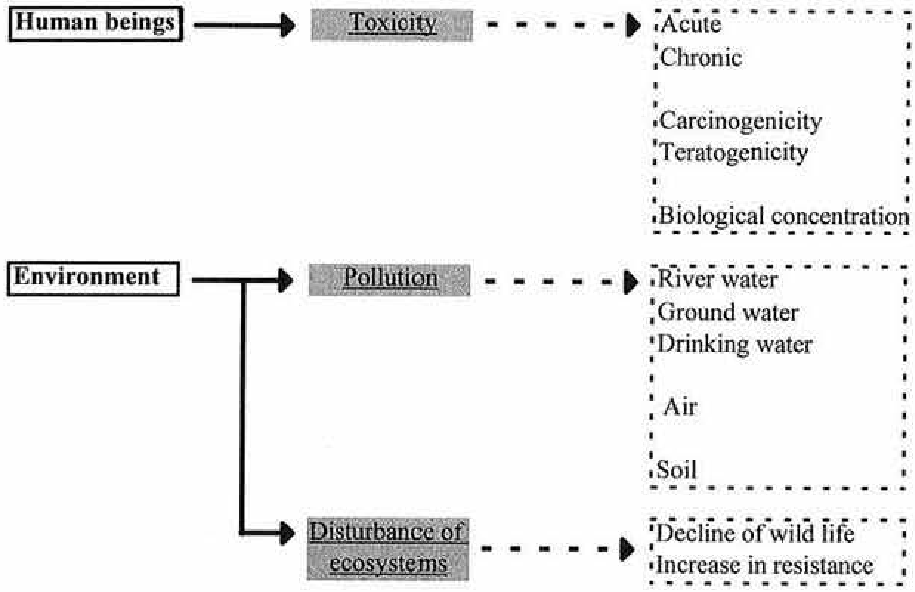

Fig. 4. Risks of pesticides

about 35% by using pesticides. Data relating to the number of working hours for rice production showed that labor productivity became 10 times higher during the 35-year period from 1950 to 1985 by using herbicides in Japan (Fig. 3).

2) Risks

Pesticide use is associated with benefits as well as risks, because pesticides markedly affect organisms and are applied in the environment. Risks of pesticides are shown in Fig. 4. Risks are divided into 2 types: (1) risks to human beings, i.e. toxicity, including acute toxicity, chronic toxicity, carcinogenicity, teratogenicity and biological concentration and (2) risks to the environment consisting of pollution and disturbance of the ecosystems. River water, ground water, drinking water, soil, and air can be polluted by pesticides. By using pesticides repeatedly, wild life declines and the number of resistant organisms increases.

Changes of pesticide properties

To overcome the risks, properties of pesticides are being changed.

1) Acute toxicity

Pesticide production based on acute toxicity in Japan is listed in Fig. 5[5]. In 1965, the rate of toxic substances in pesticides was about 30%, but, in 1988 the rate was only 4.4%, suggesting that acute toxicity of pesticides had been considerably reduced.

Table 1. Biological concentration in fish

	Pesticides[a)]	BDF[b)]
Prohibited	DDT (I)	61,600
	Aldrin (I)	10,800
	Dieldrin (I)	5,800
Authorized	Chlorpyriphos-methyl (I)	430
	Methoxychlor (I)	185
	Triclopyr (H)	31
	Fenitrothion (I)	10
	Dalapon (H)	0.6

a): I; Insecticides, H; Herbicides.
b): BCF; Biological concentration factor.

2) Biological concentration

Biological concentration of pesticides has also decreased. Biological concentration factor (BCF) in fish was investigated. BCF values of prohibited pesticides were very high, ranging from 1,000 to 10,000 units. On the contrary, BCF values of authorized pesticides were very low, ranging from 1 to 100 units (Table 1).

3) Activity

The higher the activity, the smaller the amount applied to the environment. The amount of active ingredients in pesticides applied to fields per ha from 1930 to 1982 was determined[11]. The amount applied to fields per ha decreased with time and within

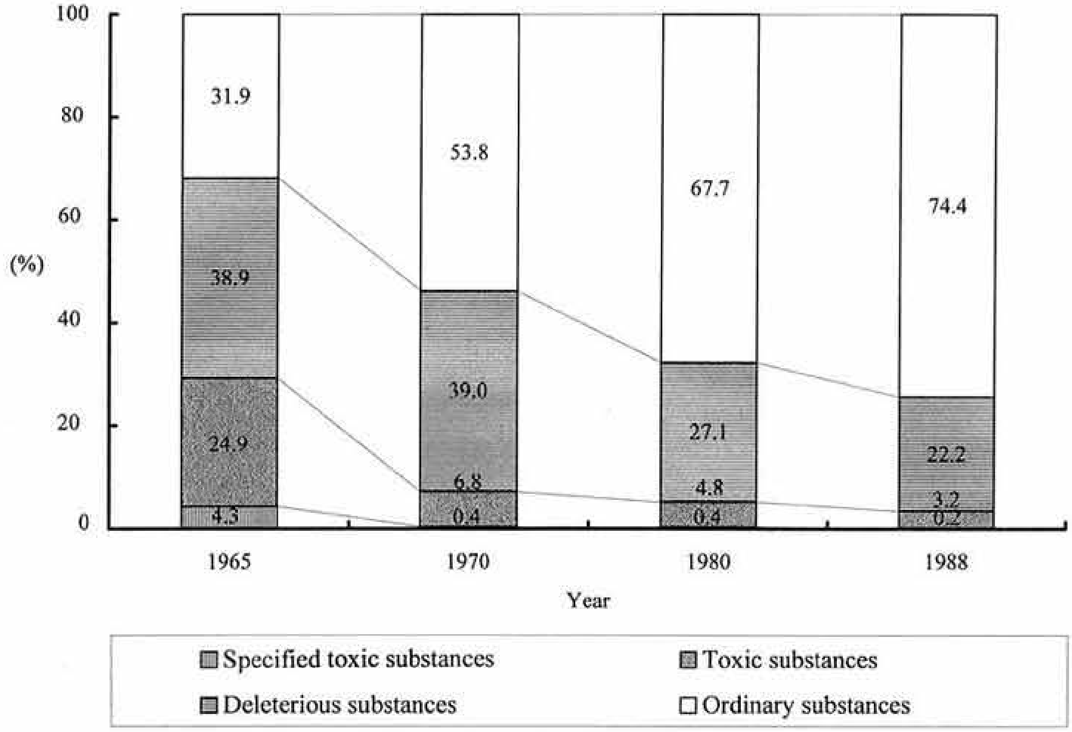

Fig. 5. Pesticide production based on toxicity

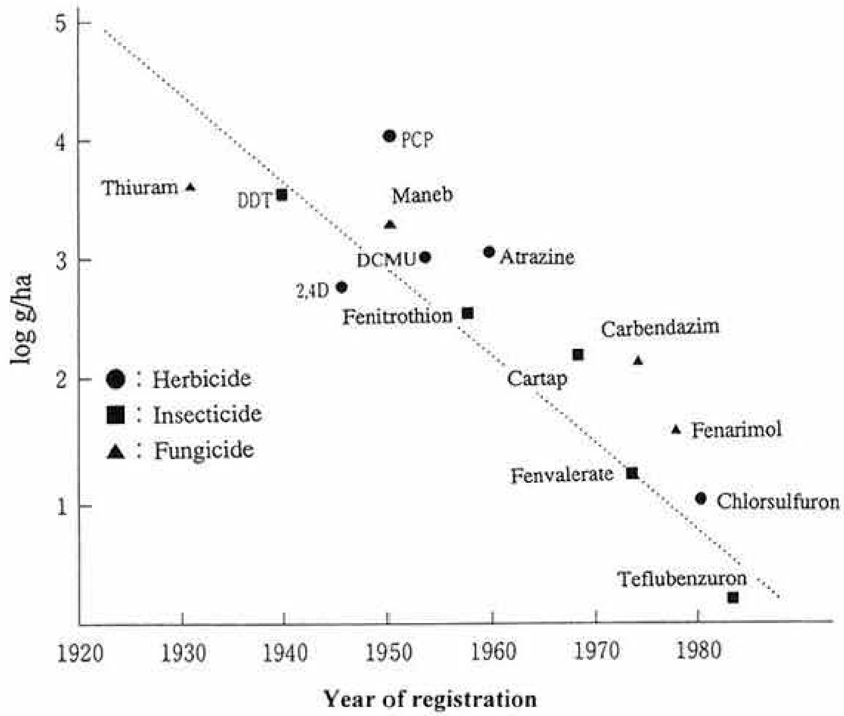

Fig. 6. Changes in the amount of active ingredients in pesticides[11]

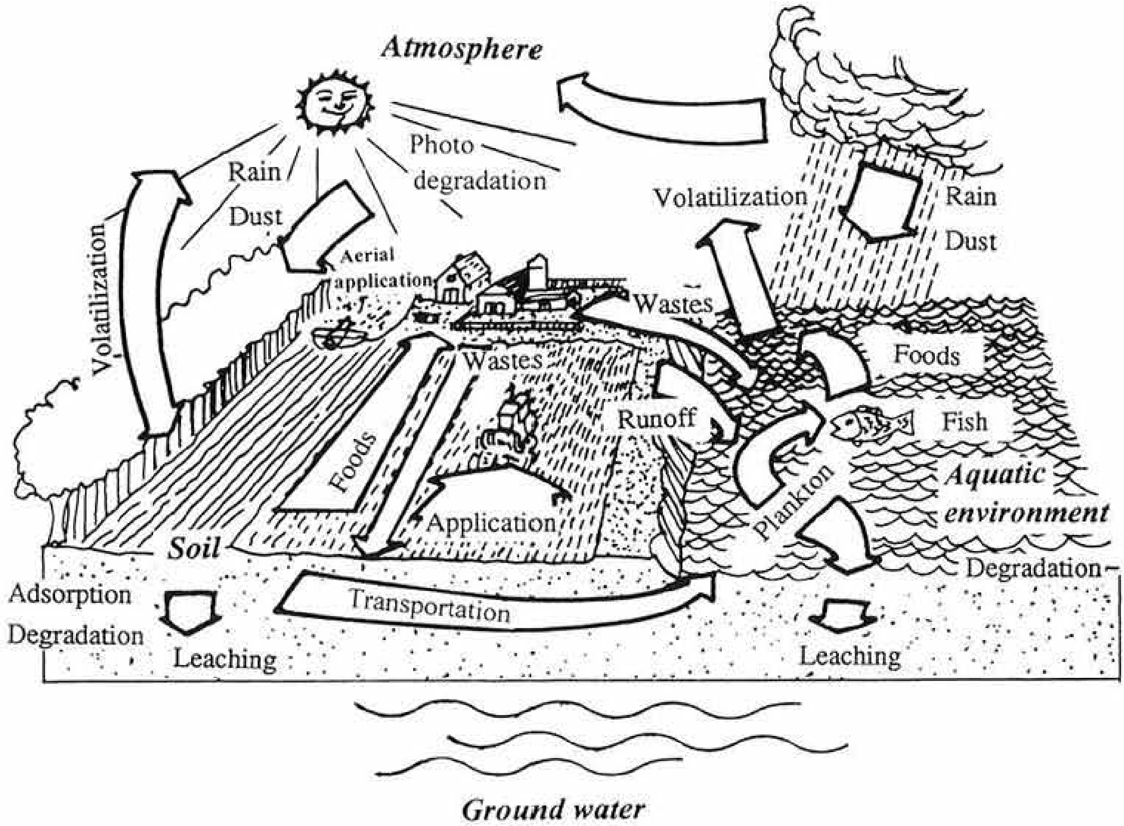

Fig. 7. Behavior of pesticides in the environment[7)]

the 50-year period, the amount decreased to one thousandth, indicating that the activity of pesticides had become a thousand times higher during this period (Fig. 6).

Effects of pesticides on ecosystems

1) Behavior of pesticides in environment

Behavior of pesticides in the environment is shown in Fig. 7[7)]. At first, pesticides are introduced to the field by ground or aerial application. In case of ground application, the pesticides are absorbed by soil particles and gradually degraded chemically and biologically. Part of them leaches down to the soil profile and reaches ground water while the other part is transported in soil to the aquatic environment. On the other hand, pesticides in the soil surface are volatilized to air and also run off to the aquatic environment. Although pesticides in the aquatic environment are degraded, the rate is lower than in soil. During this period, the pesticide concentration in organisms increases by the food chain and eventually we eat contaminated fish as food. In case of aerial application, one part of the pesticides remains in the atmosphere and is gradually subjected to photo-degradation. However, most of them fall down to the soil and aquatic environment with rain and dust. Environment in which pesticides move is divided into 3 compartments as follows.

(1) Soil environment

Most of the pesticides are spread over the soil and finally reach the soil. Repeated application test of 2 types of pesticides had been conducted for 15 years in the same upland field covered with volcanic ash soil in Japan[9,10,13)]. One type of pesticides consisted of γ-HCH (BHC) which is an insecticide and an inhibitor of the central nervous system. As a result, BHC does not inhibit directly the growth of microorganisms including its decomposers. The high persistency of BHC in upland soil is highly conspicuous. The other pesticide was chlorothalonil (TPN) which is a fungicide and SH enzyme inhibitor. TPN inhibits directly the growth and activity of microorganisms including its decomposers. Since BHC was applied repeatedly, the degradation rate increased gradually. This phenomenon was confirmed for other pesticides, for example, 2-4D, carbofuran, fenamiphos, etc.[1–3)]. On the contrary, the degradation

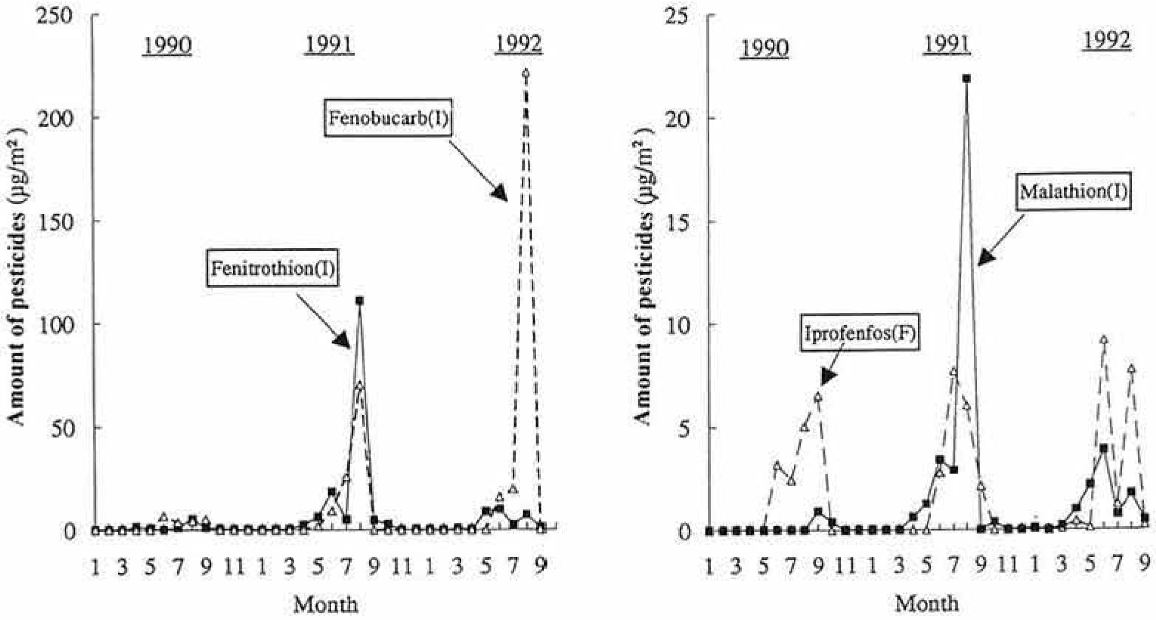

Fig. 8. Amount of pesticides detected in rainwater

rate of TPN decreased following repeated treatments. These observations indicate that the differences in properties, especially the mode of action, affect significantly both the rate and pattern of pesticide degradation in soil.

(2) Aquatic environment

The changes in the pesticide concentration in the drainage from the paddy field area in Japan were monitored[6]. During the 5-year period of monitoring, 12 herbicides, 5 insecticides and 5 fungicides were detected. The concentration level was in the range of ppb. All the herbicides were supplied to the field by ground application. The releasing patterns to the drainage were quite similar with a very low concentration (1 to 50 ppb) and long exposure time (1 to 3 months). On the contrary, most of the insecticides and fungicides were supplied by aerial application. The releasing patterns to the drainage showed a very sharp peak, that is, a high concentration (max. 1,000 ppb) and short exposure time (1 week to 1 month). However, it was not determined which releasing pattern was less harmful to non-target organisms and ecosystems.

(3) Atmospheric environment

In Japan, there are few studies on the fate and behavior of pesticides in the atmosphere. Pesticides in rainwater have been monitored since 1989 in the Kanto district[8]. Four insecticides (fenobucarb, fenitrothion, diazinon and malathion) and 1 fungicide (iprofenfos) were detected in sharp peaks in rainwater during the application period from May to October (Fig. 8). However, molinate, diazinon and fenitrothion were detected from the rainwater also in winter for unknown reasons.

2) Side-effects of pesticides on non-target organisms

Fig. 9 shows the side-effects of low concentrations of herbicides in river water on green algae (*Selenastrum*)[4]. Five kinds of herbicides are listed in the figure. Solid bar shows the concentration of herbicides. Open bar shows the growth inhibition of *Selenastrum*. In the case of molinate, no growth inhibition occurred. However, pretilachlor caused a large growth inhibition even at very low concentrations. These results indicate that not only the concentration but also the mode of action of pesticides affects appreciably non-target organisms. The growth inhibition period of *Selenastrum* by 6 herbicides was also studied. The period was about 1 and a half month. However, the effect of the period on higher level organisms in the food chain was not studied.

Side-effects occurred also in soil by degradation products[15]. A herbicide, thiobencarb (benthiocarb), was very rapidly dechlorinated in soil under anaerobic conditions and then dechlorinated thiobencarb (DTC) was produced in the soil. When the DTC concentration exceeded 1 ppm, rice dwarfing occurred. This observation indicates that the degradation product is not always safe to non-target organisms and that the degradation level is very important.

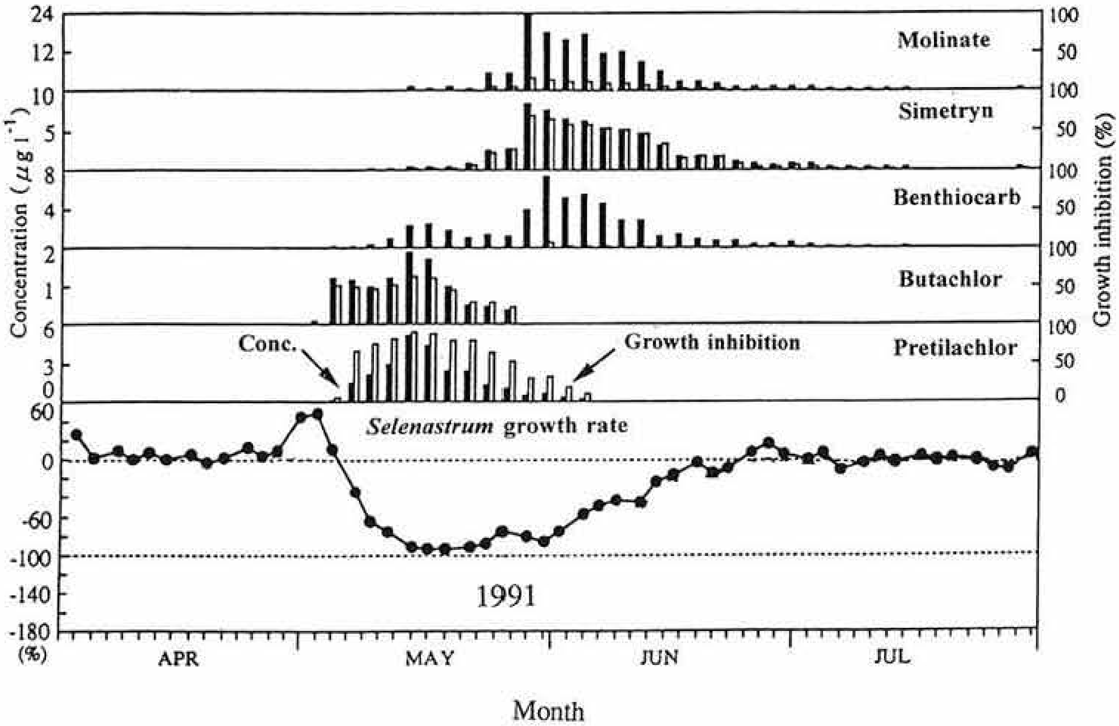

Fig. 9. Side-effects of low concentration herbicides in riverwater on green algae (*Selenastrum*)[4]

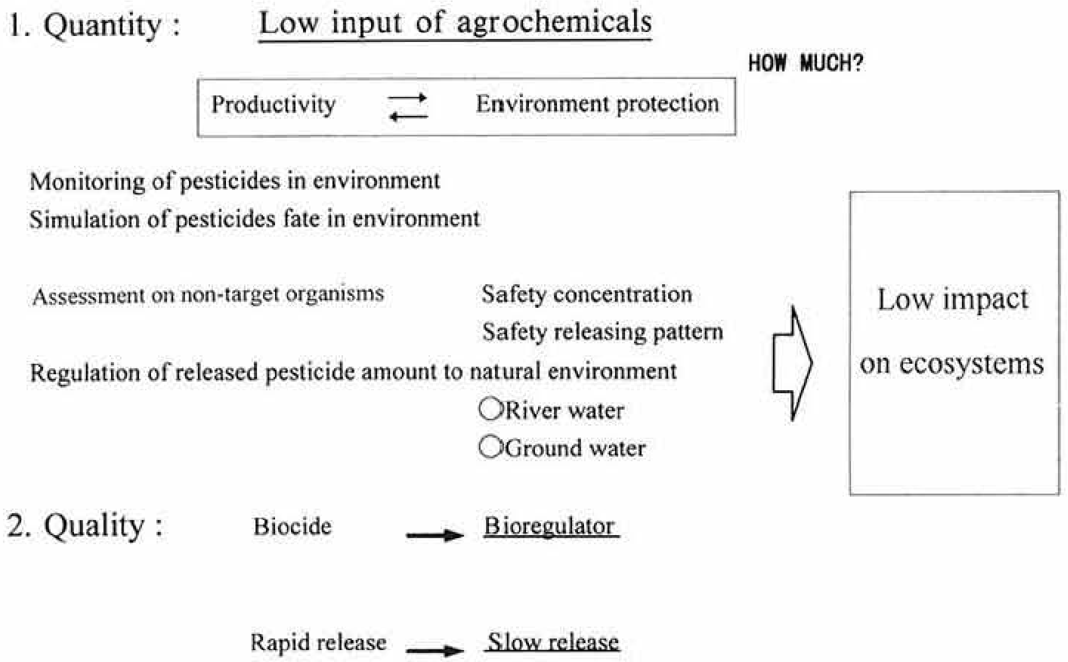

Fig. 10. Pesticide use and development for sustainable agriculture

Conclusion

Fig. 10 shows the general concept of pesticide use and development for the promotion of sustainable agriculture. To achieve this objective, quantitative and qualitative aspects of the pesticides must be considered.

At first, the quantity of pesticides is very important, because the lower the input of pesticides to the environment, the lesser the impact on the environment. To harmonize agro-productivity with environmental protection, it is necessary to (1) monitor pesticides in the environment, (2) predict the pesticide fate in the environment, (3) examine non-target organisms to confirm both safety concentration and safety releasing pattern, (4) regulate the amount of pesticides released outside of the agro-environment. Secondly, the qualitative properties of pesticides are also important. Pesticide development changes from the production of biocidal agents to bioregulators such as pheromones. Formulation of pesticides is also changing from rapid release formulation to slow release formulation such as coating or micro-capsule pesticides[14].

Through research and development, the adverse impact of pesticide use on the ecosystems may be reduced and sustainable agriculture may be achieved.

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