HISTORICAL ASPECTS OF HERBICIDE UTILIZATION FOR RICE AND ECONOMIC ASSESSMENT

Hideo CHISAKA*

Abstract

Herbicides have been widely and intensively used for rice recently in Japan. This is ascribed to the continuous improvement of herbicides, stimulated by the demand for saving labor. Several successive stages which contributed to the improvement are as follows: the introduction of phenoxy-herbicides, the development of PCP granules, the improvement of selectivity, the extension of the herbicide application period and broadening of spectra to be controlled, and the development of herbicides against perennial weeds. Weeding labor has steadily decreased for the past three decades, in relation to the expansion of herbicide use. Herbicide use in rice, however, seems to have virtually reached a limit, although new, more effective and safer herbicides may replace the current ones.

Introduction

Since the introduction of the use of the herbicide, 2,4-D for rice, for the first time in 1950, new and more effective herbicides have been developed and their use has steadily increased, as a means of saving labor and of providing efficient weed control. Recently in Japan, the term "herbicide" has been frequently used as a synonym of weed control, owing to its wide applications. In case of paddy rice, more than fifty herbicides are registered now and more than 200% of rice fields have been treated with herbicides of late.

Such an intensive and wide use of herbicides in Japan exceeds that in any other rice-producing countries. This may be attributed to the socio-economic situation and the continuous improvement of herbicide efficiency. In this paper, the history of herbicides, along with the successive stages of their development will be reviewed.

Socio-economic background

Demand for saving labor: Rice production in the past was characterized by intensive management supported by the abundance of manual power supply, and weed control was practiced three to five times in a cropping season by hand and handweeder. Handweeding, especially under hot and humid conditions was so exacting that the "liberation from handweeding" was strongly called for. Furthermore, the recent rapid progress of the industrial sector caused the exodus of the farm population to industrial sites and an increase in wages. The population engaged in farming and the dependence on farming of a farm household decreased to a half in the past two decades, as shown in Table 1. Price indices also show that wage increased thirteen times in these years while price of rice only 4 fold.

Under these circumstances, labor saving management for crop production was deemed necessary in addition to keeping or increasing the level of yield. Farming was thus moving toward the adoption of labor-saving technology such as mechanization and herbicide application.

Efficiency of chemical weeding in the early stage of herbicide development: Experimental results obtained in 1959 are shown in Table 2, in which labor and cost of weeding for rice are

* National Institute of Agricultural Sciences, Yatabe-cho, Ibaraki 305, Japan.

Table 1 Trends in some indices of farm economy.

	Year				
	1960	1965	1970	1975	1980
Members engaged in farming (% of 1960)	100	79.2	71.2	54.4	48.0
Dependence on farming* (%)	55.0	48.0	36.5	33.6	25.5
Price indices					
Wage (1960 = 1.0)	1.0	2.2	4.2	9.4	12.9
Rice (1960 = 1.0)	1.0	1.5	2.0	3.7	4.2

$$\text{* Degree of dependence on farming} = \frac{\text{Income from agriculture}}{\text{Total income of a farm household}}$$

(Sources of data: MAFF, 1981)

Table 2 Efficiency of chemical weeding in the 1959 experiment.

(MAFF, 1964)

Weeding method	Weed weight at harvest (% of non-weeded plot)	Rice yield (% of hand-weeding)	Labor man-hrs/ha	Cost of weeding* (% of hand-weeding)
Handweeding fb** hand rotary weeder	1.3	100	225	100
Hand rotary weeder fb MCPA	6.5	98	75	40
PCP fb hand rotary weeder	1.2	97	50	47
PCP fb MCPA	0.0	104	15	37
No weeding	100	79	0	0

* Total cost of labor and herbicides.
** fb = followed by.

Table 3 Trends in weeding labor and herbicide use for rice.

	1949	1954	1960	1965	1970	1975	1980
Total labor (hr/ha)	2,162	1,852	1,740	1,412	1,178	815	644
Weeding labor							
hr/ha	506	311	268	174	130	84	59
% of total labor	23.4	16.8	15.4	12.4	11.0	10.3	9.2
Herbicide-treated acreage (% of total rice fields)	0.0	14.9	33.9	96.3	159.2	221.0	244.1
Rice yield (brown rice, ton/ha)	3.22	3.09	4.01	3.90	4.42	4.81	4.12

(Sources of data: MAFF, 1982 and JAPR)

compared between traditional handweeding practices and newly developed chemical weeding. Sequential application of PCP and MCPA reduced the labor hours and the cost of weeding to less than one tenth and one third of the conventional handweeding, respectively.

Owing to such economic benefit, herbicides were widely adopted by farmers as labor-saving techniques. Practical use of PCP started in 1959 and spread to more than 60% of the total rice fields in the following five years.

Herbicides in the earlier stage of development have been replaced with newer ones, one after another since then, and the herbicide-treated acreage has steadily increased. Reduction of weeding labor, as shown in Table 3, is drastic and highly correlated with the expansion of herbicide use.

Stages of herbicide improvement

Herbicides developed in the earlier stages presented problems in many aspects such as selectivity, toxicity, period of application, weed spectra to be controlled, etc. Stimulated by the success of the use of phenoxy-herbicides and PCP, and supported by the socio-economic background, much attention and effort were concentrated on developing more effective and safer herbicides. Sequence of development is indicated as follows (figure in parentheses after herbicide's name indicates the initial year of sales).

1 First stage

Introduction and improvement of phenoxy-herbicide: The herbicide 2,4-D was introduced for practical use in 1950 followed soon by MCPA. Properties of these phenoxy-compounds are attributed to their selective phytotoxicity to plant species. In order to avoid injurious effects on rice, these herbicides are commonly applied during the middle growth stage of rice, and consequently they are not particularly effective in the control of Gramineae weeds such as barnyardgrass. Therefore, hand- or mechanical weeding was still required prior to the herbicide application, though a great deal of weeding labor was being saved.

The initial formulation of phenoxy-herbicides required direct spraying on foliage parts of weeds after drainage of the surface water in rice fields. A few years after the introduction of 2,4-D, the ester type of phenoxy compounds and their granular formulation were developed, enabling the application of herbicides in submerged fields. In spite of the fact that granular 2,4-D or MCPA is less active on weeds than the water soluble formulation, the granular formulation is now widely utilized due to the ease of application.

2 Second stage

Development of PCP granules: In 1959, PCP (pentachlorophenol) came into use as a herbicide for soil treatment effective on annual weeds including barnyardgrass. PCP acts as an inhibitor of energy formation by uncoupling oxidative phosphorylation in plant respiration and does not show substantial selectivity for plants (Fig. 2). However, the development of the granular formulation of PCP afforded safe use for rice.

Figure 1 illustrates the mechanisms of selectivity of PCP granules. PCP granules applied onto rice fields reach the soil surface without remaining on rice leaves and then disintegrate in forming a PCP active layer in the surface soil. Emergence depth of annual weeds is generally shallow enough for germinating seeds to absorb PCP. In other words, the selective herbicidal action of PCP granules is due mainly to the differences in the growth stages of rice and weeds and to the absence of contact of the toxic ingredient with foliage of rice. Most of the herbicides for soil treatment developed after PCP were formulated as granules because they cause less injury to rice and are easy to apply.

One of the serious limitations of PCP was its high toxicity to fish and shellfish. Thus, PCP was gradually replaced with newly developed herbicides less toxic to fish.

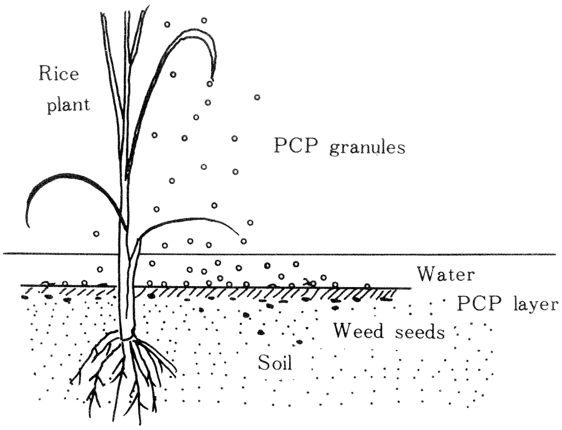

Fig. 1 **Mechanisms of selective herbicidal action of PCP granules (Arai *et al.*, 1966).**

3 Third stage

Improvement of selectivity of herbicides for soil treatment: Because PCP showed a substantially non selective phytotoxicity, it often caused injury to rice or afforded insufficient weed control under inadequate climatic and cultural conditions. In intensive agriculture, herbicides are evaluated not only in terms of their effectiveness in weed control but also in terms of their lack of toxicity to rice plants. Thus, efforts were made to improve their selectivity for rice and weeds as well as to develop herbicides less toxic to fish. As a result, herbicides for soil treatment with higher selectivity and lower fish toxicity such as nitrofen (1963), CNP (chloronitrofen) (1965), benthiocarb (1971) and chlomethoxynil (1973) were developed in succession. In Fig. 2, some herbicides are compared for their selectivity for rice and barnyardgrass, respectively.

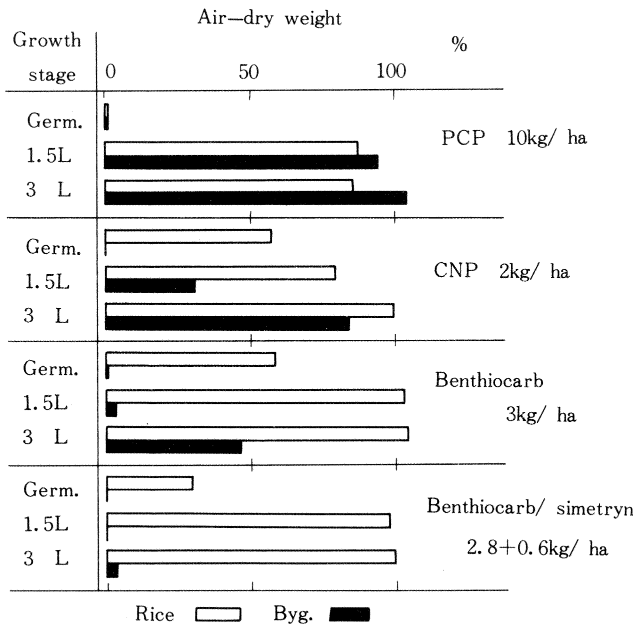

Fig. 2 **Selectivity between rice and barnyardgrass.**

Since approximately 1967, machine transplanting has gained a rapid popularity. In machine transplanting, younger and smaller seedlings are planted at a shallower depth than in traditional hand transplanting. These seedlings are generally more susceptible to herbicides, and so they need selective herbicides. Advances in the selectivity of herbicides contributed to the rapid and smooth expansion of machine transplanting. The herbicide, pyrazolate (1980) which can discriminate between rice and weeds even at the germination stage, came into practical use recently, and can be applied to water-seeded rice soon after sowing.

4 Fourth stage

Extension of herbicide application period and broadening of weed spectra to be controlled: As herbicides for soil treatment are generally effective for weeds only at the germination stage, they must be applied within several days after transplanting of rice. The transplanting season, however, is one of the busiest seasons in the farm and the farmers are likely to overlook the timing of herbicide application. Furthermore, most herbicides in those days were less effective for certain weed species, particularly if the timing of application was not appropriate.

In order to solve these problems, many kinds of mixed herbicides containing two or three active ingredients were studied, and some of them gave good results. They were called "foliage and soil treatment" herbicides, and formed a new group of post-weed-emergence soil treatment. Herbicides belonging to this group include swep/MCPA (1969), followed by benthiocarb/simetryn (1970) and molinate/simetryn/MCPB (1975), etc. They are used approximately two or three weeks after transplanting.

On the other hand, attempts were made to extend the herbicide application to puddling time, and a new application method was devised for oxadiazon (1972). In this method, emulsifiable concentrates are directly applied as droplets on the water surface after puddling without dilution with water.

5 Fifth stage

Development of herbicides against perennial weeds: Weed population in rice fields has been shifting from annuals to perennials. When manual weeding was the only means of weeding, dominant species were mainly annuals. Use of herbicides for these dominant annual weeds led to the discontinuation of manual weeding or frequent soil disturbance. Such conditions became conducive to the growth of perennial weeds.

Recently, much emphasis has been placed on the development of herbicides to control perennial weeds, and some promising compounds such as bentazon (1975), dymron, naploanilide and pyrazolate (1980) have already been produced. These compounds are mainly formulated as an active ingredient in mixed herbicides such as dymron/chlomethoxynil (1976), naploanilide/ butachlor (1982) and pyrazolate/butachlor (1982) which are supposed to control broader weed spectra with a single application.

Present status of herbicide use

More than fifty herbicides, half of which are mixed herbicides (mixture of two or three active ingredients) are registered for paddy rice nowadays. According to their application time, they are classified in three groups: pre-weed-emergence soil treatment, early post-weed-emergence soil treatment and foliage treatment herbicides. Major herbicides in each group and acreage to which they were applied in 1981 were estimated from sale amount and are listed in Table 4.

Total acreage to which herbicides have been applied in recent years amounts to more than 200% of rice fields, indicating that farmers use herbicides twice sequentially in a crop season on the average. Reasons for such an intensive use, besides labor shortage, rise of wages, high price of rice and ease of herbicide application, are as follows:

Table 4 Major herbicides for rice in 1981.

Type	Herbicide
Pre-weed-emergence soil treatment	
at puddling time	oxadiazon (16), oxadiazon/butachlor (5)
pre- or post-transplanting	chlornitrofen (27), chlomethoxynil (23) butachlor (22), chloronitrofen/dymron (10) benthiocarb/chloronitrofen (8)
Post-weed-emergence soil treatment	benthiocarb/simetryn (22), molinate/simetryn/MCPB (18) benthiocarb/simetryn/MCPB (15), dimethametryn/piperophos (9) simetryn/MCPB (4), molinate/simetryn (4)
Foliage treatment	2,4-D (9), MCPA (8), bentazon (2) bentazon/2,4-D or MCPA (2)

Figures in parentheses indicate the acreage to which each herbicide had been applied.
Expressed as percent of total rice acreage (source of data: JAPR, 1981).

Farmer's attitude: Farmers generally want to remove weeds completely from their fields. If herbicides fail to control weeds satisfactorily, farmers are compelled to remove the remaining weeds by hand which is a tedious procedure. To avoid such a trouble, farmers are apt to use herbicides excessively.

Dissemination of machine transplanting: In machine transplanting, younger and smaller seedlings are transplanted 7 to 10 days earlier than in the case of manual transplanting. As a result, the crop is exposed to weed competition for a longer period of time and the weed emergence persists longer owing to the low temperature in the early growth season. Thus, in the case of machine transplanting, sequential application of herbicides and/or the use of more persistent herbicides are required to obtain satisfactory weed control.

Increase of perennial weeds: Most of the conventional herbicides are not effective or are only partially effective for the control of certain perennials. Furthermore, as the emergence pattern of perennials is usually different from that of annuals, a single herbicide application may not correspond to the proper timing for either annuals or perennials. Sequential application of two or three herbicides is thus needed to achieve good control of weeds.

Economic evaluation of chemical weeding

In intensive and small-scale farming, new techniques of weed control are commonly evaluated in terms of cost or labor-saving but not from the standpoint of rice yield improvement. According to the agricultural statistics, weeding for rice required more than 500 man-hrs/ha in the years prior to the introduction of herbicides. This labor amount is estimated to be equivalent to more than US$1,600 as the present wage. Recent statistics indicate that the number of hours for weeding was 66 hrs/ha and the total cost of weed control amounted approximately to US$340/ha for the rice production of the year 1979.

Chemical weeding is thus highly beneficial to the farmers from the economic viewpoint by reducing the number of labor hours. Besides, chemical weed control has played an important role in minimizing the seasonal peaks of labor demand in farms, and also in contributing to the dissemination of machine transplanting.

Herbicide use for rice, however, seems to have reached a limit, as shown in Fig. 3, although new, more effective and safer herbicides may replace the current ones. Unexpected problems have

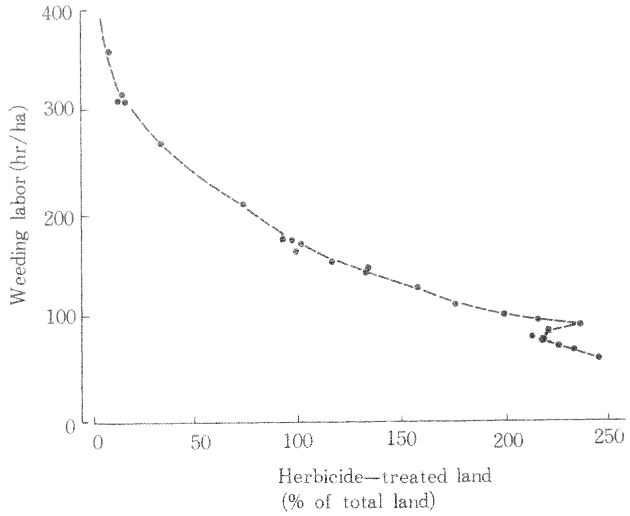

Fig. 3 Relationship between herbicide-treated land area and weeding labor hours in rice.
(Sources of data: MAFF and JAPR)

been associated with the intensive use of herbicides such as fish damage, drift hazard, predominance of herbicide-tolerant weeds, formation of phytotoxic metabolites and residues in the environment. Some of these problems which should not be evaluated solely on an economic basis remain to be solved.

References

1) ARAI, M. and MATSUNAKA, S. (1966): Control of barnyardgrass in paddy fields in Japan. *Japan Agricultural Research Quarterly* **1** (2), 5–9.
2) JAPR (Japan Association of Plant-growth Regulators) (1967–1980): Herbicide-applied acreage. *Shokucho*, various issues.
3) ———— (1981): Herbicide-applied acreage. *Shokucho* **15** (9), 31–36.
4) MAFF (Ministry of Agriculture, Forestry and Fisheries) (1964): Evaluation of research on weed control in rice. *Tech. Bull.* **26**, 30.
5) ———— (1964–1981): Survey of production cost of rice. Various issues.
6) ———— (1982): Handbook of agricultural statistics, 1982 edition. Tokyo, Japan.

Discussion

Sundaru, M. (Indonesia): In Indonesia we presently have difficulty in controlling perennial weeds such as *Paspalum distichum* (a grass weed) and *Salvinia molesta* (a floating weed). Do you have any experience in such weeds?

Answer: Unfortunately, I have no experience in these weeds.

De Datta, S.K. (IRRI): Comment: Glyphosate and paraquat in combination or sequential applications could be effective in controlling these weeds.

De Datta, S.K. (IRRI): You indicated 244% herbicide treatment per hectare. How do you envision rice control in the 1990s? Have you considered mechanical weeding?

Answer: In future herbicide use may be reduced to less than 100%, if herbicides are applied once a year or every two or three years.