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# Discovery, Development and Distribution of Paraquat-Resistant Biotype Weeds in Japan

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## 1. Introduction

In 1956, shortly after the introduction of herbicides for weed control, Harper[5] predicted that the repeated use of the same herbicide would inevitably be followed by the development of biotypes of weeds, as often occurred with insecticides and fungicides, and suggested various ways by which the grower might reduce the selection pressures on weed populations for evolution of herbicide-resistance. Since the first case of the occurrence in herbicide-resistance was reported in *Senecio vulgaris* L. by Ryan[15] in Washington State in 1968 in a nursery where triazine had been applied once or twice annually, reports on the development of resistance in various weed species to triazine and other herbicides have increased mainly in North America and Europe. According to LeBaron[13] there are 107 herbicide-resistant weed biotypes reported worldwide as of September, 1989, and this includes 57 species with biotypes resistant to triazine herbicides and 50 species with biotypes resistant to 14 other classes of herbicides. Thirteen species with biotypes resistant to dipyridilium (paraquat and diquat) have been reported in 8 conutries, of which 4 compositae weeds occur in Japan.

Because of such a drastic rise in the incidence of herbicide resistance, a Symposium on Herbicide Resistance was held at the 1989 annual meeting of the Weed Science Society of America, where 10 reports on important topics were presented.[7] This paper is to introduce and review discovery, development, and distribution of weed biotypes resistant to paraquat in 4 compositae species recorded in Japan.

## 2. *Erigeron philadelphicus* L.

*Erigeron philadelphicus* is a perennial weed which was introduced into Japan from North America in the 1920s and is now widely distributed throughout Japan (Figure 5).

In August, 1980, the author was informed by a mulberry grower that he had failed to control one of the weed species in his mulberry fields with paraquat applications. The author found that the mulberry fields had been infested with pure stands of *Erigeron philadelphicus*. Thus, the author and his co-workers were to carry out an experiment in one of the mulberry patches to determine why paraquat applications failed to control the population of infesting *Erigeron philadelphicus* and found that the population of *Erigeron philadelphicus* in the experimental patch was highly resistant to paraquat, whereas no resistance was observed when bentazone, glyphosate and MCPA were applied.[20] Development of paraquat-resistance was also confirmed by a greenhouse experiment to compare the responses to paraquat between plants originated from the experimental patch and those from a field without paraquat application history (Figure 1).

The dosage of 0.5kg active ingredient per hectare was sufficent to completely kill the green leaves of common susceptible plants. On the contrary, paraquat-resistant biotypes showed none of the symptoms observed in the susceptible biotypes when paraquat was applied at a rate of 0.5 to 2.0 kg active ingredient per hectare. They retained a few green leaves even at a rate of 16.0 kg active ingredient per hectare. The paraquat-resistant biotypes had also developed a resistance to diquat (Figure 2).

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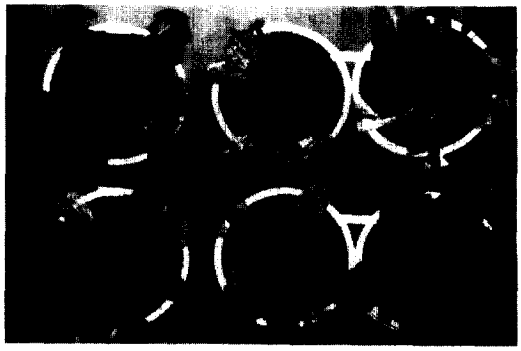


**Fig. 1.** Paraquat-resistant (bottom) and susceptible (top) biotypes of *Erigeron philadelphicus* a week after application of paraquat at rates of 0, 0.6 and 1.2 kg a.i./ha (Watanabe, 1980)

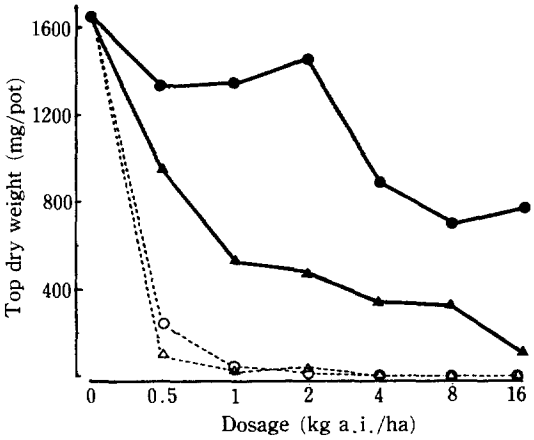


**Fig. 2.** Dose-response curve for paraquat-resistant (●▲) and susceptible (○△) biotypes of *Erigeron philadelphicus* in top dry weight 10 days after paraquat (●○) ro diquat (▲△) application.[20]

An experiment with leaf discs was carried out to determine the exact response of the paraquat-resistant biotypes to various concentrations of paraquat solutions. The result was similar to the response of intact leaves to paraquat applications, and showed that level of resistance to paraquat in the biotype of *Erigeron philadelphicus* was about 100 times higher than that of the susceptible biotypes (Figure 3).

Survey of the distribution of paraquat-resistant biotypes of *Erigeron philadelphicus* in the vicinity of mulberry patches initially found to have the resistant biotypes showed that resistant biotypes highly occurred only in the mulberry patches to which paraquat was applied for weed control, and no occurrence was

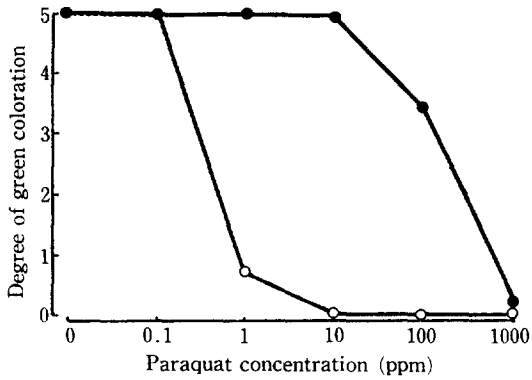


**Fig. 3.** Dose-response curve for paraquat-resistant (●) and susceptible (○) biotypes of *Erigeron philadelphicus* in retention of green color of leaf discs 48 hours after dipping in paraquat solutions.[20]

detected in the abandoned mulberry patches and unused lands without paraquat applications. The area infested with paraquat-resistant biotypes was a rather small one, being about 2.5km from north to south and about 0.7km from east to west (Figure 4). In the following year the survey on the relationship between occurrence rate of paroquat-resistant biotypes of *Erigerm Philadelphicus* and history of paraquat

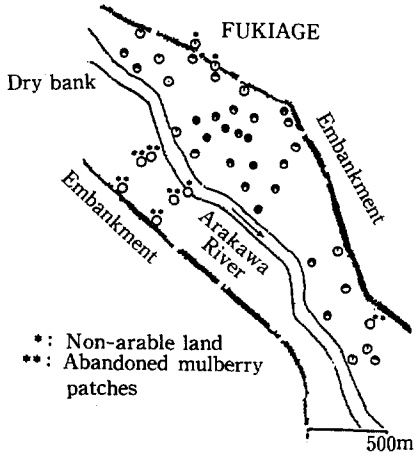


**Fig. 4.** Distribution of paraquat-resistant (●) and susceptible (○) biotypes of *Erigeron philadelphicus* in mulberry patches on the river land of the Arakawa River, where paraquat-resistant biotypes were initially found.[21] Sectors within a circle denote the ration of resistant and susceptible biotypes at the places surveyed.

**Table 1**. Relationship between occurrence rate of paraquat-resistant biotypes of *Erigeron philadelphicus* and history of paraquat applications.[9]

| Paraquat application | Site | Number of places surveyed | Mean ratio of resistant biotype |
|---|---|---|---|
| Never applied | Vacant[a] | 10 | 2.1% |
| 2-3 years ago | Abandoned mulberry patches | 2 | 0.0 |
| Sometimes[b] | Vicinity of mulberry patches | 15 | 47.5 |
| 2-3 times annually | Mulberry patches | 21 | 80.5 |

Note. Determined in April, 1982.
a : Embankment, unused land, etc.
b : Sometimes receiving paraquat due to drift or boundry applications in adjacent mulberry patches.

applications was carried out, and it reconfirmed that paraquat-resistant biotypes of *Erigeron philadelphicus* had only developed in the mulberry patches to which paraquat had been applied 2 to 3 times annually and had hardly developed in the lands without applications of paraquat (Table 1).

To know the accurate history of the development of paraquat-resistant biotypes of *Erigeron philadelphicus* a questionnaire was submitted to the growers who had cultivated mulberry patches adjacent to those in which the resistant biotypes had been initially found. The result indicated that populations of *Erigeron philadelphicus* in the fields were not resistant to paraquat when the growers began to apply paraquat for controlling them around 1970, and paraquat had been annually applied 2 to 3 times at first and then 3 to 4 times lately ; thus the first manifestation was recorded 5 to 6 years after the first paraquat applications for weed control in mulberry cultivation.[20]

Since the initial finding of the paraquat-resistant biotypes of *Erigeron philadelphicus*, those of many cases have been reported in various regions and sites in japan as seen in Table 4. In the most cases paraquat-resistant biotypes developed in the lands infested with *Erigeron philadelphicus* where paraquat had been applied for weed control.

A single dominant gene is responsible for the paraquat-resistance in *Erigeron philadelphicus*.[10] As of 1989, herbicide-rsistant biotypes, which are regarded to be paraquat-resistant, of this weed are recorded mainly in the central part of Japan (Figure 5).


**Fig. 5**. Prefectures in Japan where being regarded paraquat-resistant biotypes of *Erigeron philadelphicus* were confirmend (●) and unconfirmed(○)by questionnaire in 1989.[17]

### 3. *Erigeron canadensis* L.

*Erigeron canadensis* is a biennial weed which was introduced into Japan from North America in the 1870 s, and is now widely distributed throughout Japan (Figure 7). Paraquat-resistant biotypes of *Erigeron canadensis* were initially found in a part of the vineyard of Osaka Prefectural Agricultural Reseach Center in 1980. In 1981, all orchards where paraquat had been annually applied 2 to 3 times were infested with paraquat-resistant biotypes of *Erigeron canadensis*, and no susceptible biotypes were noticed in some of the orchards in 1982.[11]

Paraquat-dose response for paraquat-resistant biotypes of *Erigeron canadensis* is the same as for

**Table 2.** Dose-response for paraquat-resistant biotypes of *Erigeron canadensis* to paraquat and diquat in an orange grove.[11]

| Herbicide | Dose (a.i.) | Response after application 5 hours | 2 days | 5 days | 10 days | Plant height (after 30 days) |
|---|---|---|---|---|---|---|
| Paraquat | 450.0 kg/ha | +~++ | +++ | × | × | |
| | 90.0 | +~++ | + + ~+++ | + + + ~× | × | |
| | 18.0 | + | + (~++) | +~++ | ++ | 0.4 |
| | 3.6 | − | ± | ± | − | 0.6~1.6 |
| | 0.72 | − | − | − | − | 0.8~1.7 |
| Diquat | 112.5 | +~++ | × | × | × | - |
| | 22.5 | + | + + + ~× | × | × | - |
| | 4.5 | ±~+ | + + ~+++ | + + + (~×) | + + + (~×) | 0.2~0.4 |
| | 0.9 | − | ± | ± | ± | 0.5~1.4 |
| Control | | − | − | − | − | 0.6~1.4 |

Note. − : Normal, ± : Slightly yellowish in leaves, + : Brown spots in leaves and leaf tip death, ++ : Death of 1/2 of tops, +++ : Only a few stem bases surviving, × : Complete death of tops.

those of *Erigeron philadelphicus*. They required about 75 times higher concentrations of paraquat solutions than the recommended dose for susceptible biotypes in order to be killed in the orange grove infested with paraquat-resistant biotypes, and they were also resistant to diquat, as was *Erigeron philadelphicus* (Table 2). In an experiment of chlorophyll retention of leaf discs in various concentrations of paraquat solutions, paraquat-resistant biotypes were about 1,000 times more resistant to paraquat than susceptible biotypes (Figure 6).

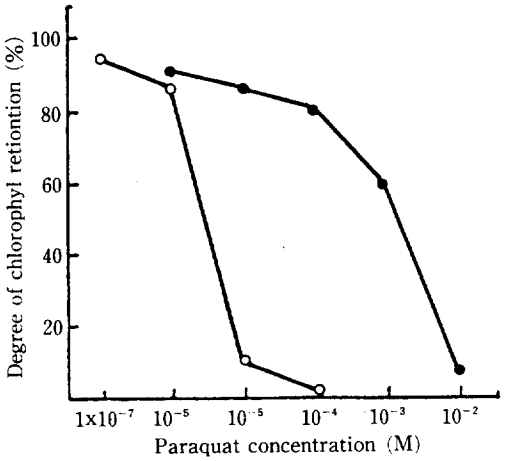


**Fig. 6.** Dose-response curve for paraquat-resistant (●) and susceptible (○) biotypes of *Erigeron canadensis* in retention of chlorophyll of leaf discs 24 hours after dipping in paraquat solutions.[5]

Survey of the development of paraquat-resistant biotypes of *Erigeron canadensis* in Osaka Prefecture in 1983 to 1985 confirmed that paraquat-resistant biotypes developed in vineyards, orchards, orange groves and chestnut groves where paraquat had been applied, whereas no occurrence was detected in lands that surrounded those orchards without paraquat applications (Table 3).

After the finding in Osaka Prefecture of paraquat-resistant biotypes of *Erigeron canadensis*, occurrence sites of paraquat-resistant biotypes increased (Table 4). By a questionnaire survey paraquat-resistant biotypes to be regarded are recorded in the western part as well as in the central part of Japan (Figure 7).

### 4. *Erigeron sumatrensis* Retz.

*Erigeron sumatrensis* is a biennial weed, reportedly, was introduced from South America into Japan in the early 1920s, and now is widely widely spread on the same sites as *Erigeron philadelphicus* and *Erigeron canadensis* throughout Japan.

Paraquat-resistant biotypes of *Erigeron sumatrensis* were initially detected in 1989 in mulberry fields located in the near site where paraquat-resistant biotypes

**Table 3**. Occurring frequency of paraquat-resistant biotypes of *Erigeron canadensis* in Osaka Prefecture.[12]

| Site | Number of places surveyed | Nunber of places in which resistant biotypes occurred | Frequency of occurrence of resistant biotypes | | |
|---|---|---|---|---|---|
| | | | Min. | Max. | Mean |
| Vineyards | 6 | 6 | 10% | 70% | 35% |
| Orange groves | 16 | 11 | 5 | 100 | 58 |
| Chestunt groves | 5 | 1 | - | - | 100 |
| Other orchards | 6 | 2 | 14 | 33 | 24 |
| Paddy, upland fields, etc. | 6 | 0 | - | - | - |
| Roadsides, Parks, Reclaimed lands, | 17 | 1[a] | - | - | 13 |

Note.
a : Reclaimed land surrounded by roange groves on withc paraquat was applied. *elp*


**Fig. 7**. Prefectures in Japan where being regarded paraquat-resistant biotypes of *Erigeron canadensis* were confirmed (●) and unconfirmed (○) by questionnaire in 1989.[17]

of *Erigeron philadelphicus* were firstly found.[3] Paraquat had been applied for weed control to the fields infested with paraquat-resistant biotypes of *Erigeron sumatrensis* ; the responses of their leaf discs to various concentrations of paraquat solutions were similar in tendency to those noted in biotypes of *Erigeron philadelphicus* and *Erigeron canadensis* resistant to it. But their incidence was low density on the whole as compared with the cases in *Erigeron philadelphicus* and *Erigeron canadensis* resistant biotypes.[3]

Development of herbicde-resistant biotypes, which are regarded to be paraquat-resistant, of *Erigeron sumatrensis* has been confirmed by questionnaire in the same sites as in the case of *Erigeron canadensis* (Table 4), but the former distribution is limited compared with the latter.[17]

### 5. *Youngia japonica* L. (DC.)

*Youngia japonica* is a winter annual or biennial native weed species and distributed throughout Japan.

Paraquat-resistant biotypes of this weed were detected in 1986 in the same mulberry fields in Saitama Prefecture as described for *Erigeron sumatrensis*, and the reaction of leaf discs of *Youngia japonica* resistant and susceptible biotypes to various concentrations of paraquat solutions has shown the same tendency as in the cases of paraquat-resistant biotypes of the above-mentioned 3 species.[2]

Outside Saitama Prefecture, herbicide-resistant biotypes, which are regarded to be paraquat-resistant, of *Youngia japonica* have been recorded by questionnaire in both Gunma and Ibaraki Prefectures in 1989 (Table 4).

### 6. Conclusion

In a questionnaire survey carried out in 1989 by Satoh et al.[17], they obtained replies of the occurrence of such herbicide-resistant biotype weed species as *Erigeron annuus* Pers. (Compositae), *Senecio vulgaris* L. (Compositae), *Sonchus asper* Hill (Compositae), *Rorippa indica* Hochr. (Cruciferae), *Poa annua* L. (Gramineae) and Nobie (*Echinochloa* species in Gramineae) excepting the above-described

**Table 4.** Deelopment of paraquat-resistant biotype weeds in Japan.

| Weed species | Earlist finding | | | |
|---|---|---|---|---|
| | Year | Location | In crop | Reference |
| *Erigeron philadelphicus* | 1980 | Fukiage ; Saitama | Mulberry fields | Watanabe et al.[20] |
| | 1982 | 4 sites ; Saitama | Mulberry fields | Hanioka[1] |
| | 1984 | Yatabe ; Ibaraki | Chestunt groves | Saka et al.[16] |
| | 1986 | 5 sites ; Saitama | Mulberry fields | Hanioka[4] |
| | 1987 | Nakanozyo ; Gunma | Konjak fields | Uchida[18] |
| | 1988 | 13 sites ; Ibaraki | Orchards, tea and mulberry fields, etc. | Usami et al.[19] |
| | 1989 | Ibaraki, Gunma, Saitama, Kanagawa, Niigata, Gifu | Mulberry, tea, upland and abandoned fields, roadsides, etc. | Satoh et al.[17] |
| *Erigeron canadensis* | 1980 | Habikino ; Osaka and Wakayama | Vineyard | Kato et al.[11] |
| | 1983 | Kobe ; Hyogo | Upland fields | Hirata & Matsunaka[6] |
| | 1985 | 20 sites ; Osaka | Orange and chestnut groves, vineyards, etc. | Kato[12] |
| | 1989 | Ibaraki, Gunma, Saitama, Mie, Yamanashi, Nara Osaka, Hyogo, Okayama, Hiroshima, Fukuoka, Miyazaki | Mulberry, tea and upland fields, orchards, roadsides, etc. | Satoh et al.[17] |
| *Erigeron sumatrensis* | 1986 | Kumagaya ; Saitama | Mulberry fields | Hanioak[3] |
| | 1989 | Ibaraki, Saitama, Kanagawa, Aichi, Osaka, Wakayama, Hiroshima, Miyazaki | Orchards, tea and mulberry fields, roadsides, etc. | Satoh et al.[17] |
| *Youngia japonica* | 1986 | Konan ; Saitama | Mulberry fields | Hanioak[2] |
| | 1989 | Ibaraki, Gunma, Saitama | | Satoh et al.[17] |

Note. : Paraquat-resistance has not been confirmed directly.

4 species. It is considered that if a more comprehensive survey is achieved, more species with biotypes resisant to paraquat may be found. Hereafter, herbicide classes and resistance needs to be confirmed with exact experimentation.

From the ahove-mentioned results paraquat-resistant biotypes are suggested to have developed under the strong selection pressure imposed with continuous several-times annual applications of paraquat in the fields infested with those weed species. Holt and LeBaron have concluded in their report at the Symposium described previously that "Recognition, prevention, and management of herbicide resistance in all agricultural situations is imperative. All the available management tools, ··· should be used to manage weeds to stop the rapid worldwide increase in revolution of herbicide resistance".[8] In order to minimize or avoid the development of herbicide-resistant biotypes

in weeds, the most important thing of many available management tools is avoiding continuous applications with a single herbicides.

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