Control of Barnyardgrass in Paddy Fields in Japan

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Introduction

Weeds in the paddy fields in Japan total 43 families with 191 species in all, about 30 species of which are pointed out as "harmful weeds".[8),9)] They are barnyardgrass (*Echinochloa Crus-galli*), Tamagayatsuri (*Cyperus difformis*), Matsubai (*Eleocharis acicularis*), Konagi (*Monochoria vaginalis*), Abunome (*Dopatrium junceum*) and so on. In these weeds, barnyardgrass can not be controlled by phenoxy-type herbicides, 2,4-D and others, but it is the most serious weed in rice culture, since the weed has almost the same growth phase as the rice plant. Damage in grain yields by the weed is very heavy because of the competition for nutrients and light. Barnyardgrasses are classified in this country as follows:

Japanese name	Scientific name	Number of chromosome
	Echinochloa Crus-galli Beauv.	
Ta-inubie	*var. oryzicola* Ohwi	36
Ke-inubie	*var. caudata* Kitagawa	54
Hime-inubie	*var. platicola* Ohwi	54
Hime-ta-inubie	*var. kasaharae* Ohwi	54

The most dominant one is Ta-inubie, and the second Ke-inubie.

Physiology and Ecology of Barnyardgrass

Emergence of weeds should be analysed from both standpoints, germination of weed seeds in soil and elongation of young seedlings of weeds.

Environmental factors having effect on the germination of barnyardgrass seeds in soil are temperature, partial pressure of oxygen, soil moisture, electric potential of soil (Eh), and growth inhibitors in soil.[6)]

Optimum temperature for germination of awaken seeds is 30–35°C, and the maximum is 45°C and the minimum is 10–15°C. Under conditions of having almost no oxygen, germination is inhibited. Optimum moisture content in soil depends upon the soil characteristics, but it usually is 70–90% of the maximum water holding capacity. In irrigated paddy fields, germination has a close relationship with the electric potential, Eh. Up to an Eh value of 300–400 mV, germination is good, but below this level it is inhibited linearly with the lowering of Eh value. This inhibition may be due to both a decrease in oxygen concentrations and formation of growth inhibitors, hydrogen sulfide and others.

On the other hand, the environmental factors having effect on the elongation of young seedlings of barnyardgrass in soil are also temperature, partial pressure of oxygen, and Eh of soil.[7)] Optimum temperature of elongation is about 30°C, but it shows slow elongation at 10°C and no elongation at 5°C. In air, elongation is normal, but below 5% in O_2 partial pressure it will be inhibited. Especially under the condition of having almost no oxygen, barnyardgrass can not elongate more than 0.5–2 cm of length and rots to die. The effect of the partial pressure of oxygen on elongation is more severe than that on germination.

The elongation of young seedling has also a close relationship with electric potential of soil (Eh). The performance is very similar to those in the case of the germination.

As a result of those facts, the depth of the emergence of barnyardgrass is very different, depending upon the moisture content of soil. In the case of 70–80% of the maximum water holding capacity of soil, the maximum depth of emergence will be about 10 cm, but it becomes about 3 cm in water-saturated soil and about 2 cm in a deep submerged condition.

In addition to environmental factors, the emergence is controlled by the state of the weed itself, that is, by both the breaking of the primary dormancy and the velocity of introduction into the secondary dormancy. The breaking of the primary dormancy is accomplished by the successive processes; low temperature in winter, variable temperature in spring and irrigation in late spring. This breaking is performed step by step. Arai and Miyahara divided it into five steps.[4] After the second step, an anaerobic condition, for instance, submerged incubation into soil at 30℃ or incubation in nitrogen gas, will break the dormancy, and the following aerobic condition will accomplish the germination.[3] If the seeds awakened from the primary dormancy are kept in O_2-deficient condition and high temperature, they will go into the secondary dormancy. The earlier the breaking of primary dormancy or the higher the temperature, the easier the introduction into the secondary dormancy.

On the other hand, Arai and Miyahara found that the seeds died in the winter season, between February and April.[5] As a result of the analysis of the reason, the percentage of dead seeds is significantly higher in awaked ones than in the dormant. This finding will draw out the idea that the development and utilization of chemical substances which can break the primary dormancy of barnyardgrass in autumn or winter will be very useful, since the application of such chemicals could increase the dead seeds between February and April and suppress the emergence of barnyardgrass in paddy fields. We now found several chemicals that are active toward this purpose, and tests for practical application is in progress.

Barnyardgrass Control by the Cultivating Methods

Depending upon the studies on physiology and auto-ecology of barnyardgrass or the study on the competition between the weeds and rice plants, practical control methods of barnyardgrass by cultivation are proposed. Some of them have been performed experimentally by farmers for a long time. Now we can control, to some extent, the weed by the cultivating methods; irrigation, plowing, and time of planting.

Irrigation method: Soil moisture content or irrigation will affect the total weight of weeds in paddy fields. The number of weeds is highest in the water-saturated condition, next is the dry state, and the lowest in the deep submerged paddy fields. The deeper the depth of water, the fewer weeds. Then it can be concluded that deep irrigation is best from the viewpoint of weed control if the other conditions permit such treatment.[1] One advantage of the deep irrigated transplanting method in rice culture (which has a long history in Japan) is in the better weed control by both the deep irrigation and the dominancy of rice plant seedlings to weeds in the early growing stage.

Plowing method: The plowing methods between harvesting in autumn and transplanting in next spring, will affect the emergence rate of barnyardgrass.[2] Plowing the dry field in the autumn will accerelate the breaking of barnyardgrass dormancy and will increase the number of dead seeds between February and April.

Plowing methods themselves also affect the emergence rate of the weed as shown in Fig. 1. In the case of shallow rotary tillage, the emergence rate of barnyardgrass will be higher than in usual rotary tillage. Deep plowing is least effective in emergence. The reason might be that the different plowing methods change the location of weed seeds in the soil, and the emergence rate is different depending upon their location as described above.

Between the transplanting method and the dry type direct-sowing method, some difference in the effect of deep plowing exists. In the

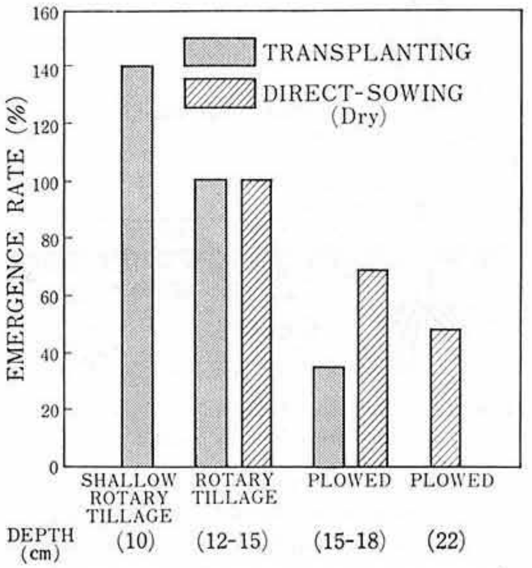

Fig. 1. Effect of tillage on the emergence of barnardgrass seeds (Arai, 1962b).

latter method, deeper plowing is required for the purpose of barnyardgrass control. As shown above, the emergence depth of barnyardgrass depends upon the soil moisture or the Eh value of soil. The maximum depth of emergence is 2 cm in the case of a deep irrigated field, but it will be about 10 cm in dry field.

Time of planting: The date of the transplanting or the sowing also has effects upon the composition of weed community and the number of weeds.[2] Thus, the date should be selected also from the standpoint of weed control.

Barnyardgrass Control by PCP-Granule Herbicide

Wonderful progress was found in chemical control of barnyardgrass by the application of PCP (pentachlorophenol) - granule herbicide. After World War II, 2,4-D and other herbicides introduced by U.S.A. were improved in their formulations for the purpose of utilization in paddy fields and contributed to the chemical control of broad leaf weeds. However, barnyardgrass and others could not be controlled by 2,4-D, and this was a serious

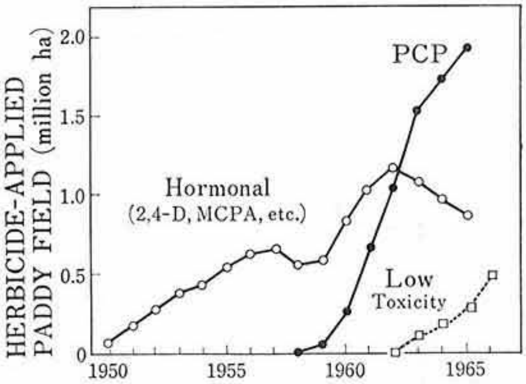

Fig. 2. Annual changes in area of herbicide-applied paddy field in Japan.

problem. To solve the problem, many herbicides were screened, and PCP-Na-granule herbicide was found to be most effective, safe and economic one.[11] The PCP-sprayed area has been increasing as shown in Fig. 2. Total area in paddy fields is 3.2 million ha. PCP-containing herbicides were applied to about two million ha of paddy fields in 1964, which is two thirds of the total paddy fields. Usually, 3 kg of 25% PCP-Na granule herbicide are applied per 10 ares of paddy fields in a submerged condition 5–7 days after transplanting (active ingredient, 750 g per 10 ares). Application is performed by hand or portable hand-driven sprayer.

Mode of Action of PCP

PCP is also famous as a fungicide or a mollusicide in which the mode of action of this chemical is supposed to be in the uncoupling of oxidative phosphorylation in respiration. It has also been supposed that the mode of action of PCP to higher plants will be the same as the former. Matsunaka found that PCP decreased the P:O ratio in the oxidative phosphorylation of cauliflower mitochondria to 50% at a concentration of 3×10^{-6}M.[10] Accerelation of O_2-uptake is one of the special properties of the chemicals so-called uncoupler, and that is the case in PCP even to a higher plant. In the existence of 3×10^{-5} M PCP, the oxygen uptake by young roots of rice plants was accerelated to a level of 170 % as shown in Fig. 3. This concentration

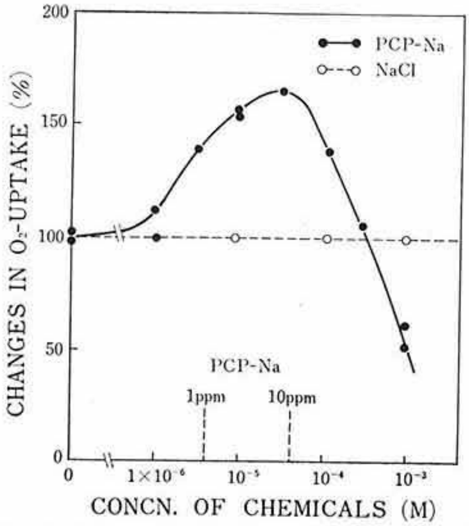

Fig. 3. Effect of PCP-Na on the O_2-uptake of excised rice roots (Matsunaka, 1965).

corresponds to those in practical paddy fields sprayed with PCP herbicide.[10] It may be concluded that PCP can uncouple the oxidative phosphorylation in respiration of weeds, and they are killed by the abnormal accerelation of their respiration.

Such inhibitors of energy formation as the uncouplers in oxidative phosphorylation usually have wide utilities as a fungicide, a herbicide and so on; on the other hand they do not show good properties in their selectivity. However, PCP-granule herbicide can be

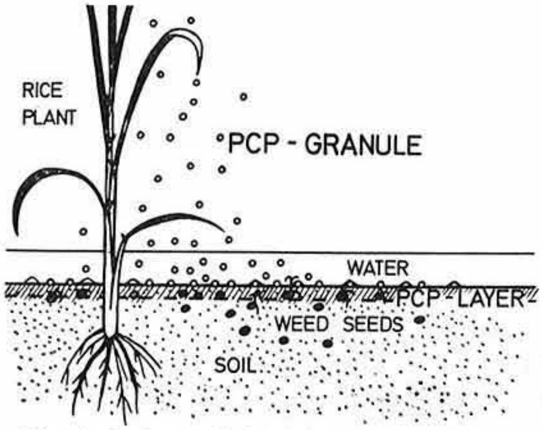

Fig. 4. PCP-granule herbicide in rice culture by the transplanting method.

safely used for the purpose of weed control in the transplanting culture of rice plants. How should we explain this discrepancy? What is the mechanism of the selectivity of PCP-granule herbicide in rice culture? It is explained by Fig. 4. Granular PCP-herbicide does not remain on the leaves of rice plants, but goes onto the soil surface through the water layer. Then the granule absorbs water and swells, and is spread over the soil surface. Usually this herbicide is caught by the soil and does not go deep in soil. As shown above, almost all seeds of barnyardgrass and also other weeds will germinate at the depth of soil containing PCP, and should be killed by this herbicide. On the other hand, the growing

Table 1. Low Toxicity Herbicides for Rice Culture

Name	Chemical Name	Formulation*	Dosage (active ingredient g/10 ares)
MCPCA	2-methyl-4-chlorophenoxy-aceto-*o*-chloroanilide	2.5%G	50～75
NIP	2,4-dichlorophenyl-4'-nittro-phenylether	7.0%G	210～280
CNP	2,4,6-trichloropheny1-4'-nitro-phenylether	7.0%G	210～280
DBN (dichlobenil)	2,6-dichlorobenzonitrile	(45.0%W. P. 3.0%G	67～90
DCBN-3	2,6-dichlorothiobenzamide	(50.0%W. P. 3.0%G.	75～100
DCPA (propanil)	3,4-dichloropropionanilide	35.0%E	350～385
Prometryne	2,4-bis(isopropylamino)-6-methylthio-*s*-triazine	1.5%G	30～90

* G: granule, W.P.: wettable powder, E: emulsion.
All herbicides except propanil are applied to deep-submerged paddy fields.

point of rice plants is located in the safety-zone and do not suffer any injury.

Barnyardgrass Control by Low Toxicity Herbicides.

By reason of the mode of action, PCP showed high toxicity to fish and shell-fish. In 1962, we had some trouble with fish damage by PCP flowing out from paddy fields into shallow lakes or the sea, but only in the case of heavy rainfalls. Then new herbicides having low toxicity to fish were developed as shown in Table 1. In 1966, the low toxicity herbicides may be sprayed on over 10% of the paddy fields in Japan, especially in the districts having fish problems. Biochemical studies on the mode of action of these new herbicides are also in progress.

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