Studies on Ecology and Control of Barnyardgrass (*Echinochloa oryzicola* Vasing.) and Other Annual Weeds in Paddy Fields

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INTRODUCTION

For the rational weed control methods, these are requisite to elucidate the ecology of weeds which are being studied, to examine the effectiveness of various measures of weed control based on the ecological knowledges and to establish the effective weed control measure. From these standpoints, the author has been studying on weed control in paddy fields, mainly aiming at the elucidation of the ecology of *Echinochloa oryzicola* Vasing. (≒*E. crus-galli* Beauv. var. *oryzicola* Ohwi) which is a representative noxious weed in paddy fields in Japan. The study was commenced when the author began to work at the Kanto- Tosan National Agricultural Experiment Station, and it has been continued during his works at the Central Agricultural Experiment Station, the Kyushu National Agricultural Experiment Station and the National Agricultural Research Center, except the period at the Office of Agriculture, Forestry and Fisheries Research Council of Ministry for two years.

The author would like to express his heartfelt thanks to his elders and colleagues for their kind guidances and cooperations. Especially, the author has recieved the great guidance from Dr. Masao Arai who was the head of laboratory when he started the work on weeds. Also the author recieved many usefull instructions from Prof. Dr. Kenji Ito. The above peoples are greatly acknowledged. The author wish to express his best appreciation to the members of Korean Society of Weed Science who gave him this precious opportunity.

I. ECOLOGY OF *Echinochloa oryzicola*

2,4-D was introduced into Japan after World War II and distributed since 1950, after confirming its effectiveness to weed control in rice production of this country. As its practical application, establishment of effective control method to *E. oryzicola* had become important subject to be solved urgently, because 2,4-D could not control Gramineous weeds well. This was the reason why the author started the studies on the ecology of *E. oryzicola*, which had been major species among several close relations of barnyardgrass growing in paddy fields of Japan.

In order to clarify the factors concerning emergence of this weed, the investigations for elucidation of seed dormancy, which was essential to make clear the viability of buried seeds, and of environmental factors controlling germination and emergence were carried out. For these purposes, materials were collected from the population of *E. oryzicola* growing abundantly in and around paddy fields of Konosu area in Japan.

1. Seed Viability in Soil

The seed of *E. oryzicola* has strong shattering habit when matured. Just after removed from panicle, they are in the primary dormancy and do not germinate at all even if suitable conditions

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were given. With the progress of maturing, primary dormancy of seed becomes deep. Seed dormancy is resulted by caryopsis in itself and not by glumes (Fig. 1). The seeds in primary dormancy can absorb water upto the same content of seed awakened from dormancy just before germination.

Awakening of dormancy is influenced by many factors such as temperature, soil moisture, gas component conditions and so on. It is also promoted by the treatment such as low- and high-temperature, storage in nitrogen without oxygen, burying into submerged soil etc. When placed on the moistened filter paper or in the upland soil moisture under optimum temperature for germination, it is observed that dormancy of partially awakened seed became deep again (Fig. 2~4). By desiccation, awakened seed returns rapidly to the state of dormancy again. The degree of this dormancy is less deeper than that of seed at just maturing (Table 1).

By the results of investigations mentioned above, several steps are recognized in the process of awakening from primary seed dormancy. These steps on awakening are proposed as shown in Table 2. And it is considered that the primary seed dormancy of *E. oryzicola* in the actual paddy field can be awakened successively by low temperature from late autumn to early spring,

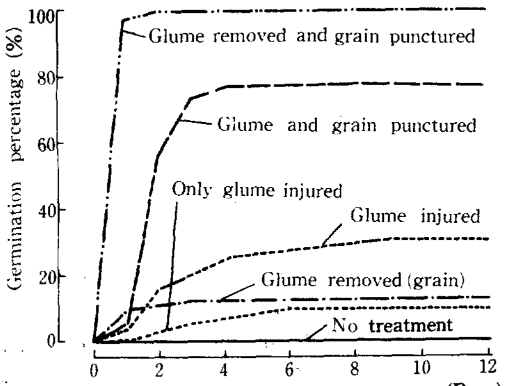

Fig. 1. Effect of various treatments of periderm of primary dormant seed of *E. oryzicola* on dormancy awakening

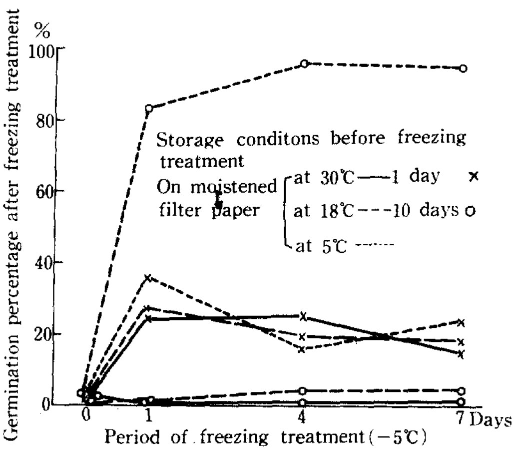

Fig. 2. Differences in the depth of primary dormancy of *E. oryzicola* seed with temperature during storage judged from freezing treatment

Table 1. Effect of desiccation on the awakening of primary dormant seed

A. Seed awakened by low temperature storage

Methods of desiccation (4 days)	Germination percentage at 30℃ after desiccation
Air dried at 3 to 5℃	9%
Air dried indoors	3
Air dried indoors after being sun dried for 2 hours	3
Control (moistened filter paper at 3 to 5℃)	93

B. Seed awakened by placing in the submerged soil

Germination percentage after placing in the submerged soil	Germination percentage at 30℃ after being air dried indoors for 3 days	Germination percentage at 30℃ after being air dried for 15 days followed by storage in the submerged soil
99.5%	1%	100%

Table 2. Stage of awakening of the barnyardgrass seed from primary dormancy

Stage of awakening	Germination on the moistened filter paper: 30℃	Germination on the moistened filter paper: Alternated temperature	Breaking of dormancy by freezing	Breaking of dormancy of seed stored in submerged soil
1st	none	none	none	none
2nd	none	none	none	awakened
3rd	little	little	almost all awakened	〃
4th	a few	almost all	〃	〃
5th	all germinated	all germinated	—	—

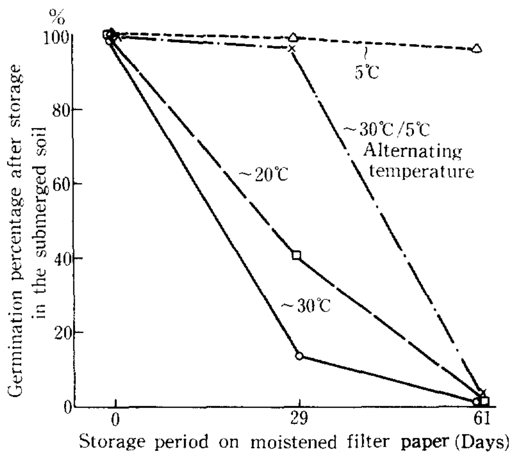

Fig. 3. Differences in the depth of primary dormancy of *E. oryzicola* seed with temperature during storage judged from storage seed in the submerged soil

fluctuation in temperature at early spring and start of submergence at the beginning of rice cultivation.

If seed awakened from primary dormancy were buried into submerged soil, it comes to show the dormancy again (Fig.5). This induction to the secondary dormancy is affected by awakening time of primary dormancy and storage temperature of seed. In the every case that awakening time is early and storage temperature is at 30℃, suitable for germination, secondary dormancy is induced more quickly than in other cases (Fig.6).

Although secondary dormancy can be awakened by almost similar factors as that of primary dormancy, it is different from the case of primary dormancy that secondary dormancy is awakened more quickly by storage in upland soil moisture than in submerged soil, under low temperature condition (Fig.7).

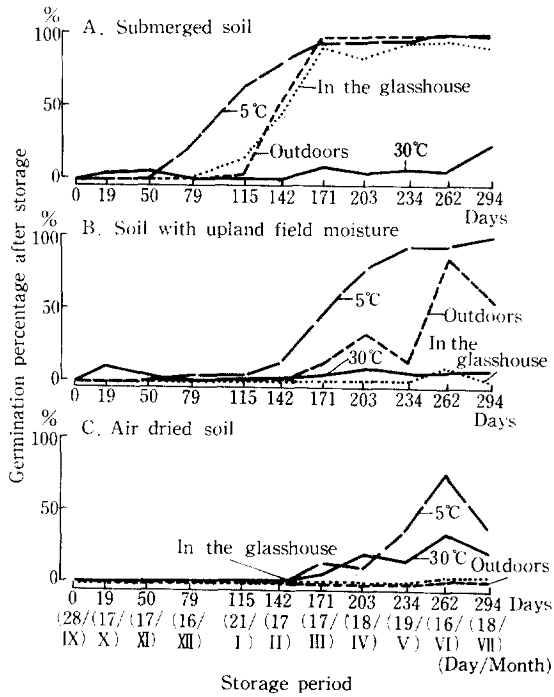

Fig. 4. Effects of soil moisture and storage temperature on awakening primary dormancy of *E. oryzicola* seed (deeply dormant seed)

According to results on secondary dormancy mentioned above, performance of seed in the actual paddy field can be summerized as follows. Seed awakened from primary dormancy is induced into secondary dormancy by the factors of high temperature and submerged soil during summer season. Secondary dormancy awakens with low temperature from late autumn to early spring and start of submergence at the beginning of cropping season, similarly to awakening the seeds in primary dormancy.

In the investigations on primary and secondary

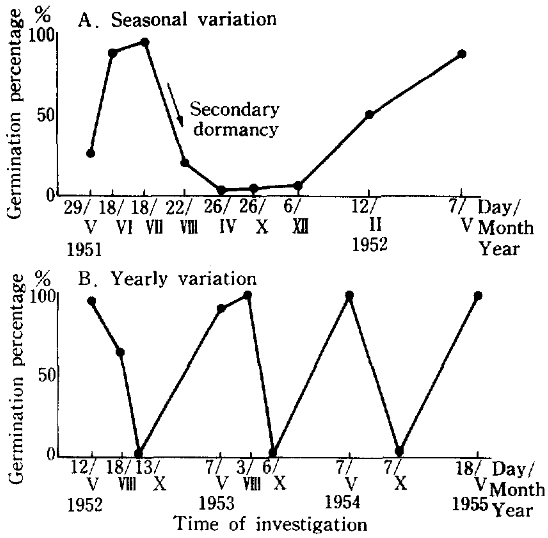

Fig. 5. Variation in germination percentage of *E. oryzicola* seed in the submerged soil

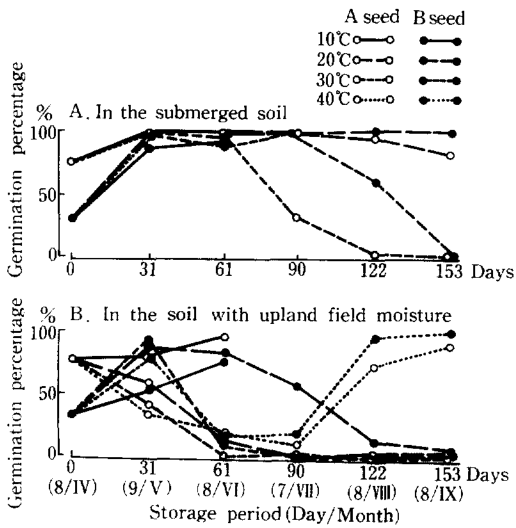

Fig. 6. Differences in the inducement of *E. oryzicola* to secondary dormancy with previous conditions, soil moisture and storage temperature

dormancy, many seeds are found dead in the process of dormancy awakening in the field. Therefore, the relationships among seed extinction in the process of awakening and previous conditions, soil moisture condition and storage temperature were investigated. Under the conditions such as seed in almostly awakened, upland soil moisture, adequate supply of water and

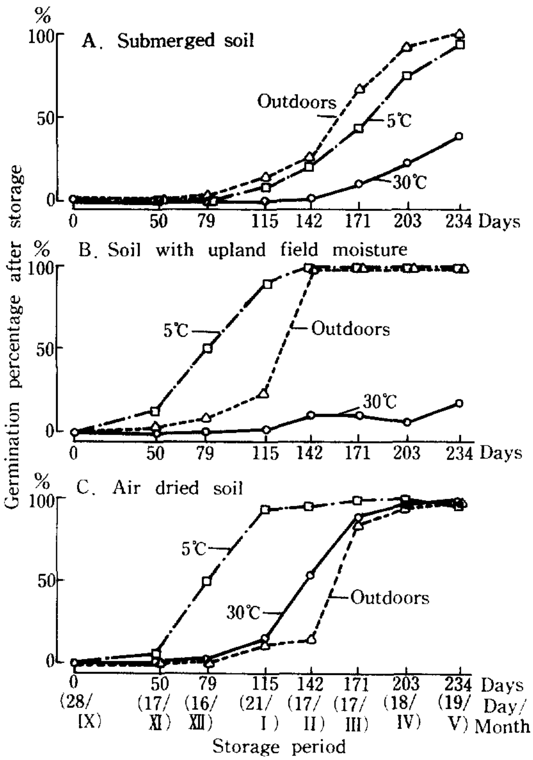

Fig. 7. Effects of soil moisture and storage temperature on awakening secondary dormancy of *E. oryzicola* seed (deeply dormant seed)

oxygen, and low soil temperature below germination temperature(5~10℃), dead seeds are produced much more(Fig.8). Namely, the result suggests that occurence of dead seed in actual paddy field must be affected mostly by soil moisture conditions from late autumn to early spring.

Based on the results of fundamental studies on seed dormancy, surveys on the seed viability of *E. oryzicola* were conducted under the condition of actual paddy field. As for the seed viability in the imperfectly drained field of Konosu, the number of viable seeds is decreased mainly by their death in the process of dormancy awakening during the first year. And at the spring of 2nd year of being shed, viable seeds are rarely observed(Fig.9).

Another investigation was carried out to compare the state of viability of seed between ill-drained field under submerged conditions through-

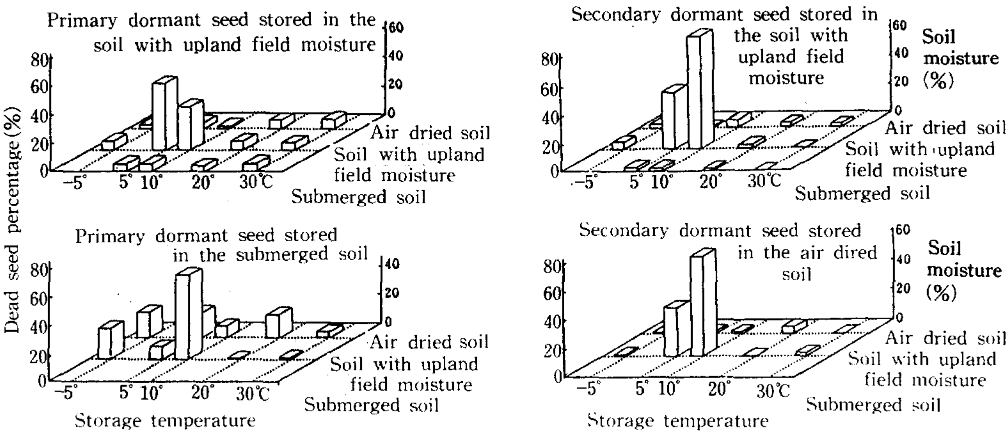

Fig. 8. Relationsnips among previous conditions, soil moisture, storage temperature and incidence of dead seed in the process of dormancy awakening of *E. oryzicola* seed

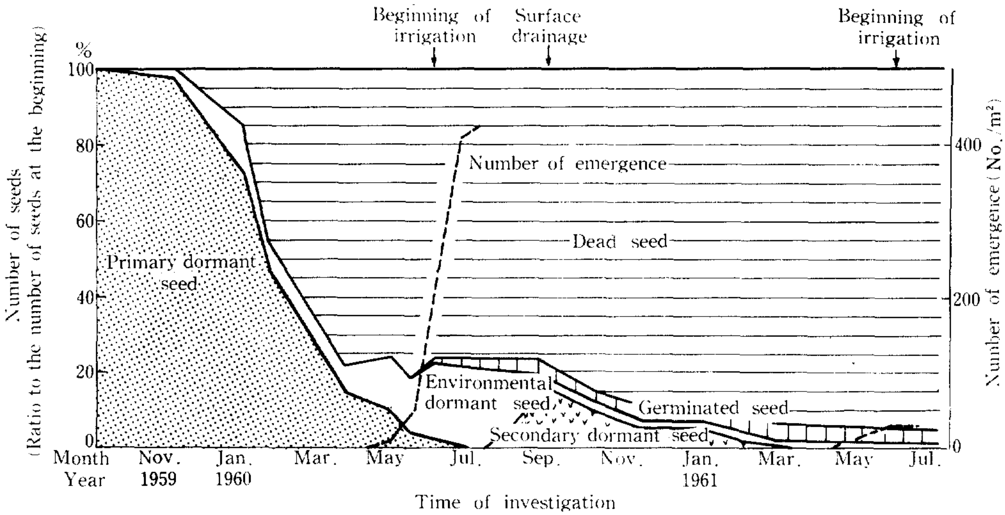

Fig. 9. Variation in the state of survival and emergence of *E. oryzicola* seed in imperfectly drained field

out the year and well-drained field where was submerged only during rice cropping season. The number of viable seeds in well-drained field seems to be similar to that in imperfectly drained field as mentioned above. However, the decrease in the number of viable seeds in ill-drained field is not caused by their death in the process of awakening, but mainly by their germination. About a half of the number of seeds produced in the first year is found still survival even in spring of the 3rd year(Fig.10).

Furthermore, the effects of methods of autumn plowing on the viability of seed were examined in the well-drained field. Then, the earlier plowing and earlier mixture of seeds into plowed soil the rapidder awakening seed dormancy, and the more numbers of dead seeds produced(Fig.11). Also, the submergence in well-drained field affects the awakening of seed. Namely, earlier submergence resulted in rapid awakening and simultaneous germination.

These results obtained from the survey on seed viability in actual field are well agreed with the experimental results mentioned earlier. Then, the

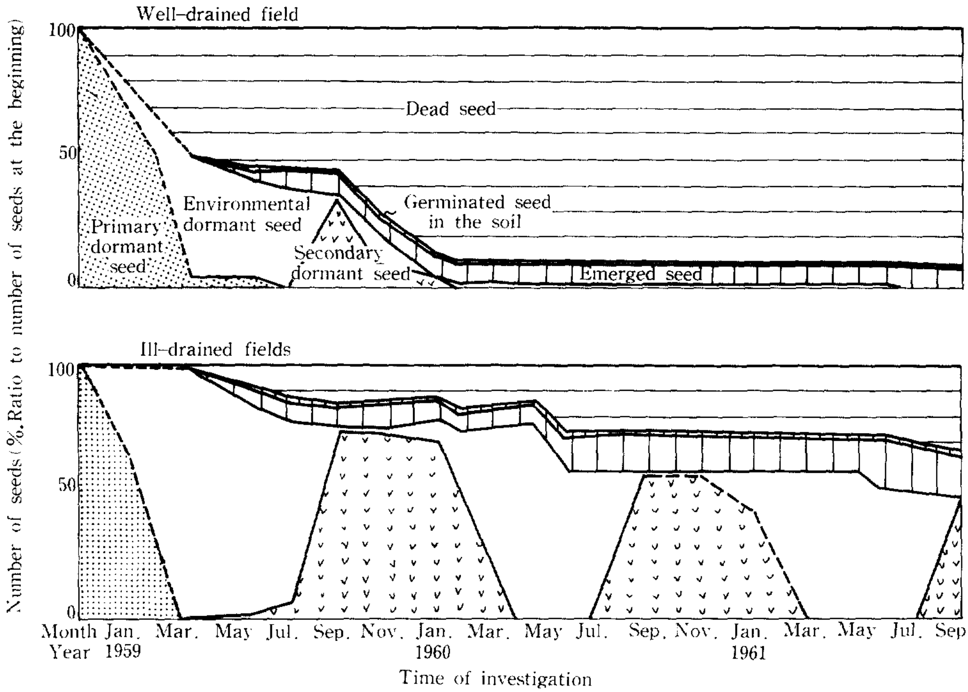

Fig. 10. The state of survival of *E. oryzicola* seed in well-drained and ill-drained fields

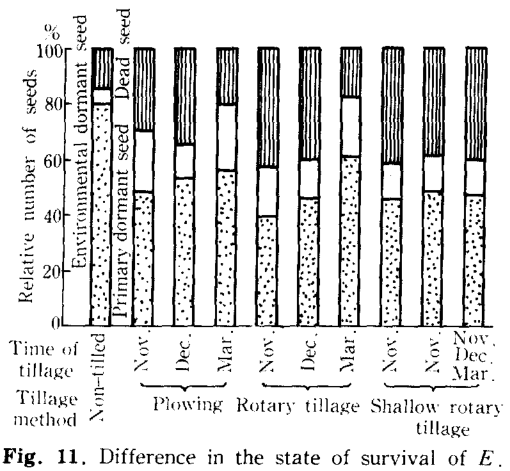

Fig. 11. Difference in the state of survival of *E. oryzicola* seed in spring with tillage method between autumn and spring (whole layer)

seed viability of *E. oryzicola* under field condition can be considered to be attributable principally to the dormancy which is controlled by **the changes in** soil moisture and in their distribution in the soil, with soil temperature fluctuating by seasonal changes.

Considering the results of investigations concerning seed dormancy and survey on seed viability in field, Schematic description of existing state of seed of *E. oryzicola* in paddy field is proposed in Fig.12, especially in connection with the environmental factors. **Soil moisture and soil temperature** are the most significant factors affecting seed viability in the soil.

2. Emergence and Environmental Factors

In order to clarify the factors controlling emergence of weeds, its process should be examined separately into the two stages. One is the germination stage in which plumule or radicle emerges from embryo and another is subsequent elongation stage of the plumule in the soil. As for the relationships between germination and environmental factors, temperature, gas conditions, soil moisture and redoxi-potential were examined respectively.

As regards the germination stage, the optimum germination is a given by the temperature at 30 to 35℃, the lower limit is 10 to 15℃, and the higher limit is 45℃ respectively. Though the

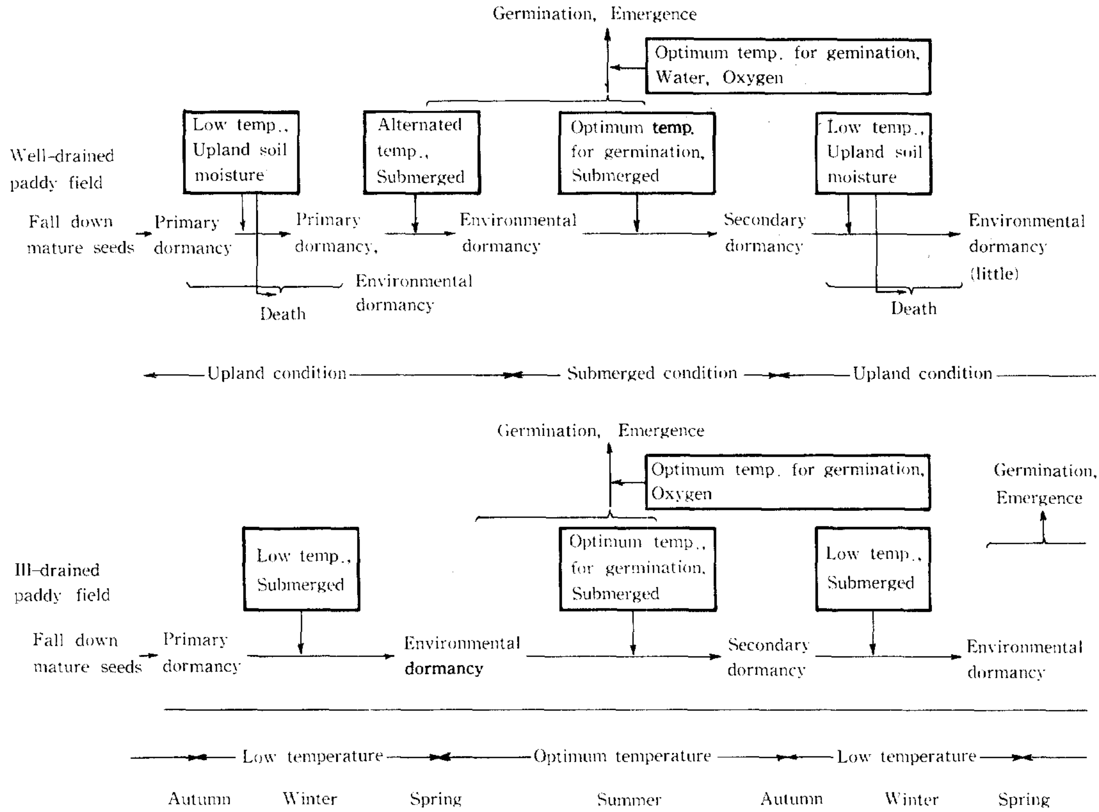

Fig. 12. Schematic description of existing state of barnyardgrass seeds in paddy field

alternated temperature never affect the germination percentage of seeds which are completly awakened from dormancy, low temperature treatment in alternating causes the delay of germination (Fig. 13). The germination is inhibited by the absence of oxygen, but is not affected by any levels above 5% oxygen (Fig. 14). At levels below 400 mV of soil Eh, the germination percentage declines linearly with the decrease in Eh (Fig. 15).

As for the elongation stage of plumule, its maximum elongation in dark is measured approximately as 10 cm, the optimum elongation is given at around 30℃ and it can elongate slowly even at 10℃. In respect with oxygen partial pressure, the elongation is good in atmosphere condition, is poor at levels below 5% oxygen and is stopped in nitrogen gas where plumules died young are observed (Fig. 16). The elongation in the submerged soil is remarkably retarded at levels below 300 mV of soil Eh (Fig. 17).

Subsequently, the relationships among soil moisture and temperature, and germination and emergence were investigated. The emergence percentage is controlled principally by the elongate ability of plumule in the soil, for which high moisture and aerobic conditions are suitable (Fig. 18).

These results of investigations concerning emergence strongly suggest that the emergence of seed after dormancy awakened is regulated by the factors such as their distribution in the plowed soil, soil moisture and soil temperature. In consider ation with the relationships between environmental factors and viability of seeds as discussed in the preceding section, it can be said that the emergence of *E. oryzicola* seed under field conditons is regulated by their distribution in the

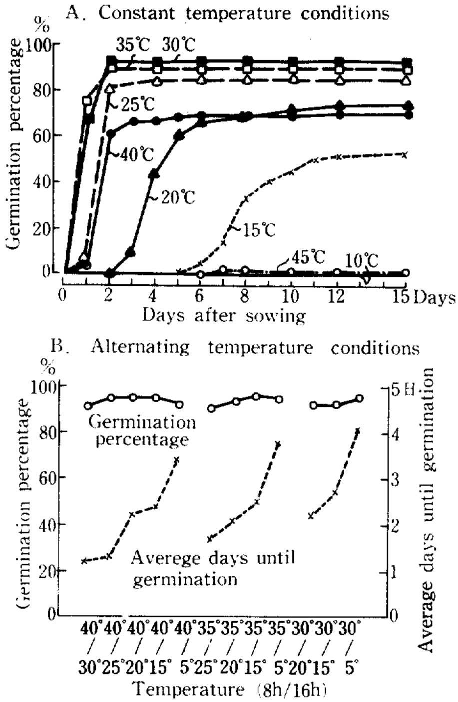

Fig. 13. Germination of *E. oryzicola* seed and temperature

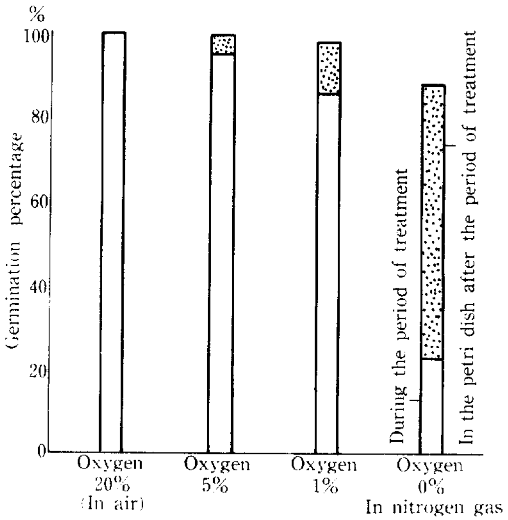

Fig. 14. Effect of oxygen partial pressure on germination of *E. oryzicola* seed

plowed soil, soil temperature fluctuating with seasonal change and soil moisture depending on drainage conditions, rainfall and irrigation systems.

The ecological and physiological studies on *E. oryzicola* mentioned here, have been carried out

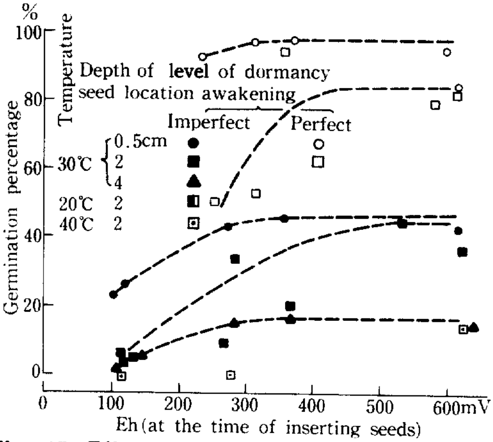

Fig. 15. Effect of soil Eh on the germination of *E. oryzicola* seed

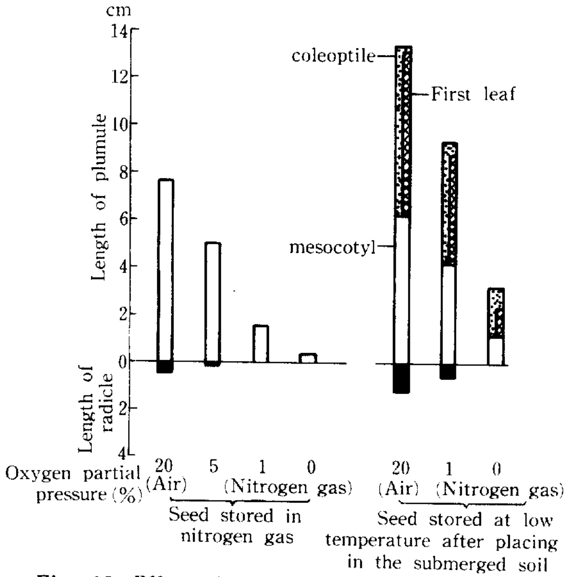

Fig. 16. Effect of oxygen partial pressure on the elongation of plumule and radicle

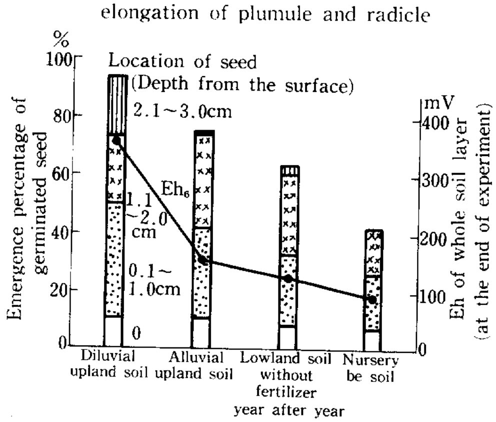

Fig. 17. Effect of soil Eh on the emergence of germinated seed

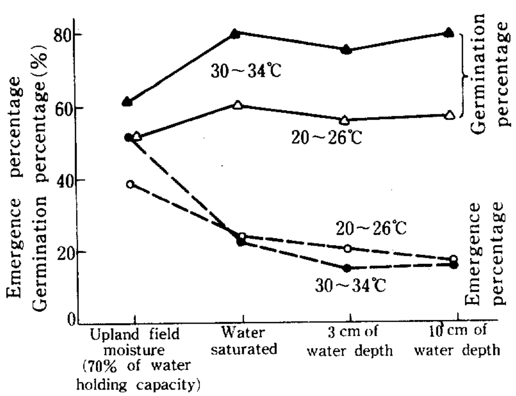

Fig. 18. Relationship between soil moisture and **temperature** and the emergence of *E. oryzicola*

using only one strain collected in Konosu area. As well known, **barnyardgrasses** growing in paddy fields include some kinds of close relations such as *E.crus-galli* Beauv. var.*formosensis* Ohwi, *E. crus-galli* Beauv. var.*crus-galli* and *E.oryzicola* Vasing. (=*E.crus-galli* Beauv. var. *oryzicola* Ohwi). Besides of differences in biological characteristics among them, even within the same taxonomical group, many bio- or eco-types differing in habit have been recognized according to their **localities**. Based on the above results, further studies should be necessary to clarify the significance of inner or interspecific variations in ***Echinochloa*** species, viewed from their control.

II. ANNUAL VARIATION IN EMERGENCE OF ANNUAL MAJOR WEEDS

In recent years, advanced weed control techniques, especially the development of effective herbicides, have realized to control annual weeds completely without any survivals and to prevent them from producing seeds. However, with this advancement, establishment of rational control **methods has become very important problem. In order to clarify their performance in the soil, study for long term has become needed on longivity of seeds of annual weeds shed and buried in the paddy field For this purpose, an investigation on yearly emergence of annual weeds was commenced in 1973 at Kyushu Naional Agricultural Experiment Station, by using plowed top soil where numerous seeds of 7 kinds of annual weeds were shed under different rice cropping seasons and water levels in paddy fields. However this investigation has been continued up to date, interim results of first 8 years can be summarized as shown in Figure 19.**

The number of yearly emergences varied according to species of weeds and water levels of fields. The earliest decline in the **number** of emergences is observed with *E.oryzicola* and this phenomenon is remarkable in well-drained field. Since the 6th year, *E.oryzicola* has not emerged at all even in ill-drained field. The second earliest decline is observed with *Monocholia vaginalis* var. *plantaginea*, and the number of emergences has become very few, year by year. Although other kinds of weeds varied in their numbers of yearly emergences with water levels of field, they can emerge abundantly in certain fields even in the 8 th year.

From these results, it is essential that almost of annual weeds should be the objects of control over several years after seeds shedding.

III. CONCLUSION-STRATEGY FOR RATIONAL CONTROL TO ANNUAL WEEDS

The perfomance of seeds concerning with dormancy and viability in the soil of paddy field **is discussed on the representative annual weed,** *E. oryzicola*. And longivity of seeds is also discussed on several kinds of annual weeds. Figure 20 suggests the differences in propagation system between annual and perennial weeds in paddy field. As for perennials, the number of emergences in the spring is regulated directly by the amounts of mother plants remained at the last harvesting time of rice. On the other hand, no significant relationship is recognized between the number of emergences in the spring and that of plants remained in the previous autumn as for

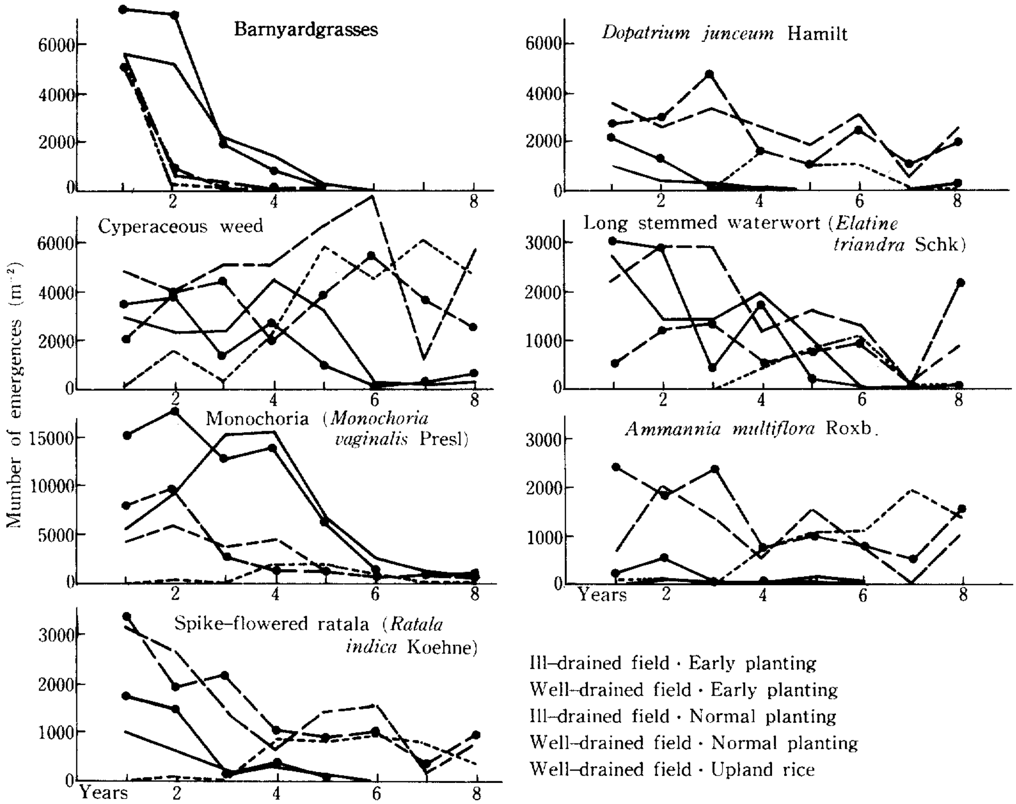

Fig. 19. Yearly variation in the emergence of main annual weeds

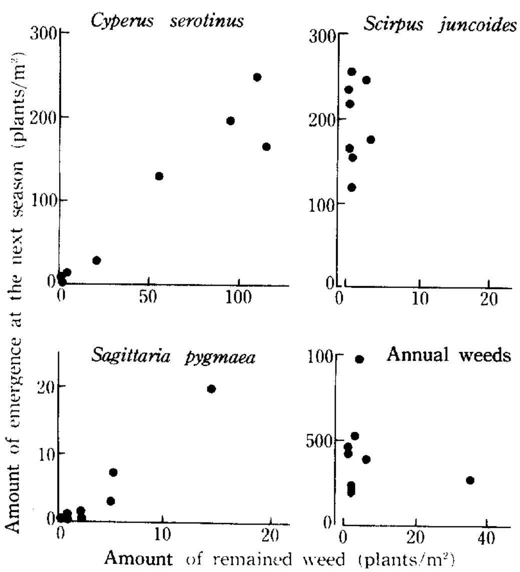

Fig. 20. Relationship between remained weed and amount of emergence at the next cropping season in paddy field

annual weeds including some perennials such as *Scirpus juncoides* subsp. *juncoides*, which propagates mainly by seed. This is the most important difference between annuals and perennials depending on the length of persistency of their propagules.

Since the number of emergences of annual weeds is regulated not only by that of mother plants at last harvesting time, but also that of survival seeds in the seed bank of soil, the strategy for the rational control to annual weeds can be considered as followes. Once seeds were produced or transfered in the field, continuous control practices should be necessary during several years, even if weeds were controlled completely in every year.

Through the further research activities on forecasting the number of emergences, diagnosis of weed damage, ecological and biological habit and so on, establishment of the successful control techniques to annual weeds will be expected in the near future.

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