Biology and Control of Perennial Weeds in Paddy Fields

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INTRODUCTION

Perennial weeds in rice paddies have become a problem since the late 1960's in Japan. The acreage infested with perennial weeds rapidly increased perhaps because of the widely spread of transplanting with young seedlings, early transplanting or increase of the farming as a side job. Their control is one of the serious problems. These days, the acreage is rather increasing though many effective herbicides have been developed and used in Japan. It is characterized by the increase of the number of the species of perennial weeds and of the acreage of paddy fields with more than two perennial species infestation.

In this paper, current research status for ecology and control of perennial paddy weeds is discussed in relation to their emergence in fields.

MAJOR PADDY PERENNIAL WEEDS AND THEIR FIELD EMERGENCE

In Japan, weeds of which emergence is found in cultivated land are estimated 450-500 species ; of these weed species, perennial weeds account for one-third of lowland weeds, and for half of the upland weeds. Those shown in Table 1 are major troublesome weeds at present. *Scirpus juncoides*, *Eleocharis kuroguwai*, and *Sagittaria trifolia* tend to increase in rice paddies. Total acreage of perennial paddy weeds covers more than 3, 700, 000 ha, which accounts for more than 150 percent of total acreage of paddies (Fig. 1). Of these perennial paddy weeds, *Scirpus juncoides* and *Sagittaria pygmaea* are commonly seen all over Japan ; *Scirpus nipponicus* and *Leesaria oryzoides* have become serious weeds in Tohoku district and Hokkaido, respectively.

ECOLOGY OF THEIR PROPAGATION

1. Propagation types and organs

Weeds reproduce themselves by two main ways : seed propagation and vegetative propagation. Perennial weeds are diversified in their reproduction ; some of them propagate only by vegetative organs such as tuber and rhizome, others propagate by both seed and vegetative propagule (Table 2). For example, *Sagittaria pygmaea*, *Eleocharis kuroguwai* and *Oenanthe javanica* propagate only by vegetative propagules, *Scirpus juncoides* and *Alisma canaliculatum* usually reproduce by seeds in rice paddies. Reproductive organs are classified into seven different types : runner, rhizome, tuber, corm, bulb, brood bud and root tuber. Each tuber of *Sagittaria trifolia* has only one bud on the top and if this bud is removed, the plant withers. *Sagittaria pygmaea* and *Eleocharis kuroguwai*, however, bear several lateral buds in addition to one apical bud. This apical bud is dominant over the other lateral buds, but even if this apical bud is removed, remaining other lateral buds can easily sprout. This makes it difficult to control these kinds of weeds.

The characteristics of vegetative propagules of major perennial paddy weeds are shown in Table 3.[11,13] Formation times of these vegetative propagules are affected mainly by daylength and

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Table 1. Major perennial weeds in paddy field in Japan

Type of growth	Weed	Propagules	height	form
Non-clonal growth	*Scirpus juncoides* var. *ohwianus*	Seed, * Over win ....g bud	M	t
	Alisma canaliculatum	Seed, * Over wintering bud (Basal corm)	M	r
	Sagittaria trifolia	Tuder, * Seed	M	r
Rhizome type	*Sagittaria pygmaea*	Tuber, * Seed	Ŝ	r
		Rhizome, * Seed	Ŝ	t
	Cyperus serotinus	Tuber, * Seed, Over wintering bud	L	e
	Eleocharis kuroguwai	Tuber, * Seed, Over wintering bud	Ĺ	e
	Scirpus planiculmis	Tuber, * Seed, Over wintering bud	L	e
	Scirpus nipponicus	Tuber, * Seed,	L	t
	Leersia oryzoides	Rhizome, * Seed, Over wintering bud	Ĺ	t
	Potamogeton distinctus	Bulb, * Seed	S	b, p
Prostrated type	*Oenanthe javanica*		M	p, b
	Paspalum diotichum	Runner, * Rhizome, Seed	L	p, b
Free-floating type	*Azolla japonica*	Dormant bud	Ŝ	n
	Spirogyra arcla	Zygospore	Ŝ	n

Note : 1) * Main propagules. 2) Plant height (cm) : Ĺ, More than 80 ; L, 60-80 ; M, 40-60 ; S, 20-40 ; Ŝ, Less than 20. 3) Growth form : e : Erect form ; p : Procumbent form ; t : Tussock form ; r : Rosette form ; b : Branched form ; n : Natantia form ;

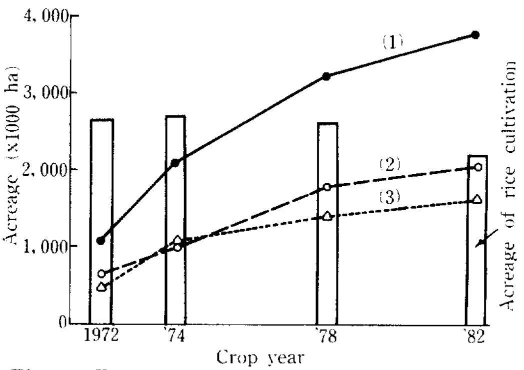
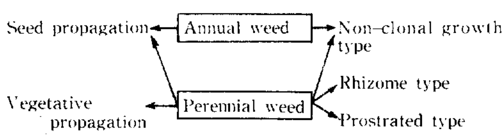


Fig. 1. Estimated acreage infested with perennial paddy weeds (JAPR),* (1) Total acreage with overall weeds, (2) Broad-leaf weeds. (3) Cyperaceous weeds.
* The Japan Association for Advancement of Phyto-Regulators

temperatures after their emergence ; the amount of those reproductive propagules formed is variable depending upon the cultivated conditions around them. However, *Sagittaria pygmaea*, one of the day-neutral weeds almost regularly form tubers, that is, 50-60 days after sprouting, even if the sprouting times vary. As for other weed species, the later they sprout, the shorter period of tuber formation they cover. They generally respond just as short-day plants though they differ in degree, and they form tubers during the ripening period of rice plant.

Table 2. Life form and propagation patten

Migrule form	Life form	Type of growth



Sagittaria pygmaea and *Cyperus serotinus* form their tubers intensely in the comparatively shallow part in the soil of 5-10 cm deep. On the other hand, *Potamogeton distinctus* form bulbs deeper in

Table 3. Characteristics of vegetative propagules of major perennial weeds in paddy fields

Items \ Weeds	*Sagittaria pygmaea*	*Cyperus serotinus*	*Sagittaria trifolia*	*Eleocharis kuroguwai*	*Potamogeton distinctus*
Soil depth of tuberization (cm)	5-6	5-10	7-15	10-15	15-20
Number of Propagules produced per m^2	2,000 ~3,000	1,000 ~2,000	500 ~2,000	1,000 ~1,500	500 ~1,000
Number of days from sprouting to tuberization	50-60	90-100	110-130	100-120	120-125
Minimum temperatures for survival (C)	-7	-5	-7	-7	-7
Dormancy	—	—	+++	+++	+
Longevity (Years)	2-3	1-2	1-2	5-7	2-3

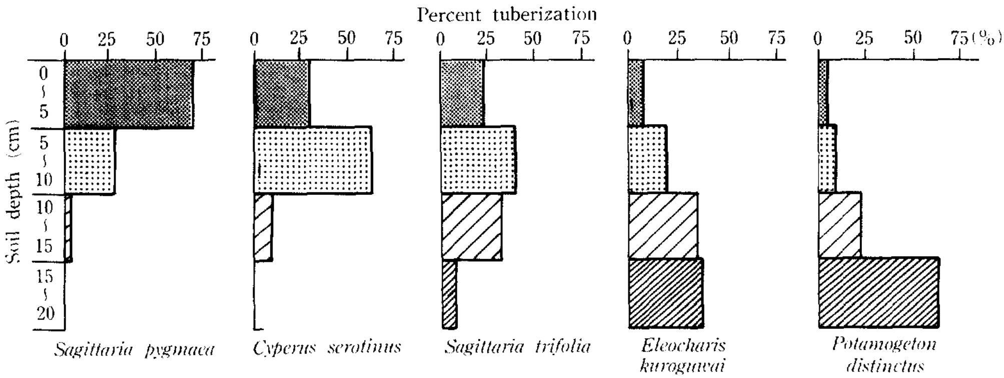


Fig. 2. Distribution of tuberization in soil. (Kusanagi *et al*. 1975)

the soil near the ploughpan. *Eleocharis kuroguwai* and *Sagittaria trifolia* form their tubers comparatively deep position on the soil; they show various perpendicular distribution of tuber formation in the soil (Fig. 2).

It generally tends that the weed species of which tubers are located in shallower part in the soil form more vegetative propagules in number; and the number is variable depending on light shading (Fig. 3).[5,7] Especially in ordinary planting with high planting density with late maturing varieties, it is quite smaller compared with the one in sparse or early planting.[6] It is said that *Scirpus juncoides* which sprouted from over wintering bud in the paddies after rice harvesting produces from several to more than ten times as much seeds as the ones which propagate

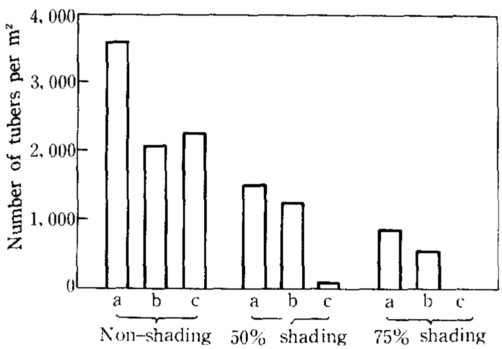


Fig. 3. Effects of fertilization and shading on tuberization of *Sagittaria pygmaea*. (Itoh er al. 1978). The plants were transplanted on June 18, shaded from July 9 to Oct. 20. Amount of fertilizer applied, a : 2kg/a of N, P and K respective, b : 1kg/a, c : Non-fertilization.

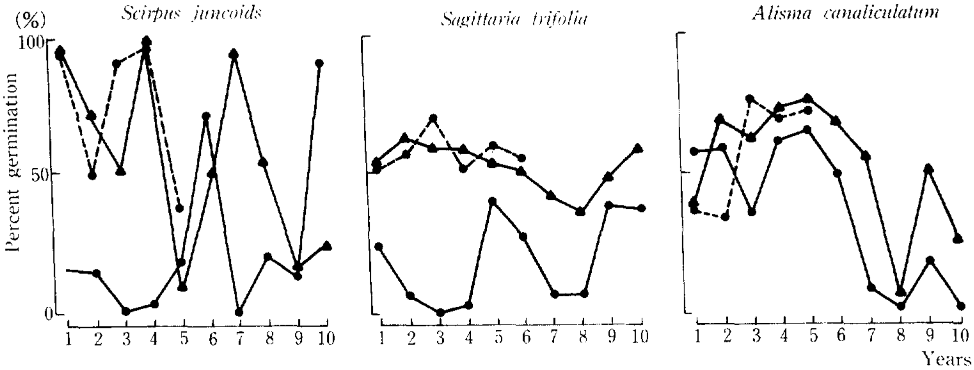


Fig. 4. Change of germination percentages of three species of perennial paddy weeds buried in the soil (Chisake *et al*. 1985). —◆— Well-drained paddy field, —●— Ill-drained paddy field, --●-- Upland field.

by seeds.[18]

Vegetative propagules have far higher water contents than seeds. Therefore, they are more susceptible to low temperatures and dry condition; they die when the temperature falls to below -5~-7℃.[12] Moreover, they cannot survive under dry condition. The vegetative propagules with water content at about 70 percent die when their water content decreases to about 30 percent. So, in order to kill them by drying up, it is enough to expose those propagules on the surface of soil by ploughing for two or three fine days. Owing to the above reasons, less perennial weeds of which vegetative propagules are formed in shallower part of the soil are distributed in high latitudes. However, in the snowy areas, no small perennial weeds are seen; it is because the temperature on the snow surface is about 0℃, and under the ground it is rather higher than that, which is high enough for their survival. In addition, the soil contains a lot of moisture. Therefore, they can easily survive through the winter under these conditions.

2. **Longevity of vegetative propagules and the movement in the soil.**

The longevity of weed seeds and of vegetative propagules are variable depending to the weed species and soil moisture. In general, gramineous weed seeds have shorter longevity than cyperaceous and broad leaved weed seeds. The seeds of *Scirpus juncoides* and *Sagittaria trifolia* survive in the soil for over ten years(Fig. 4).[11] On the other hand, life span of vegetative propagules is generally short. For example, *Cyperus serotinus* and *Sagittaria trifolia* can live only for one or two years, *Sagittaria pygmaea* and *Potamogeton distinctus* for about three years.[13] The tubers of *Eleocharis kuroguwai* survive the longest of these, for 5-7 years, but most of them can live only for about three years. Their tubers both old and young are kept unsprouted in the soil; there are also parts of a tuber which have already sprouted (Fig. 5).[4] In other words, the tubers of *Eleocharis kuroguwai* living in the soil are variable

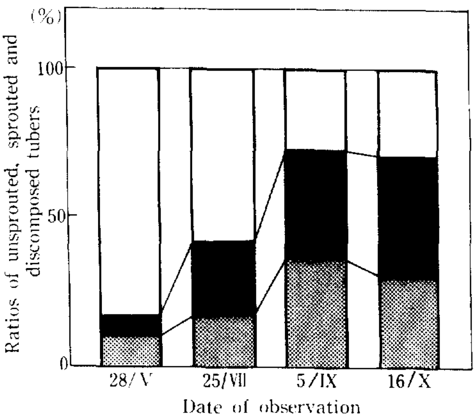


Fig. 5. The movement of tubers of *Eleocharis kuroguwai* in paddy field (Honma *et al*. 1981). □……Unsprouted tubers, ■……Sprouted tubers, ▒……Discomposed tubers. Date of puddling: June 20.

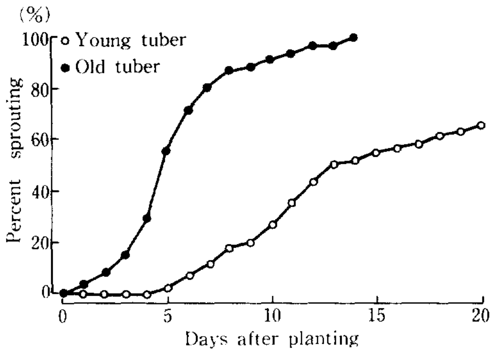


Fig. 6. Sprouting speeds of old and young tubers of *Eleocharis kuroguwai* (Yamagishi et al. 1969)

in age;[26] some of them are in dormancy, others are not. Therefore, they sprout irregularly over a long period. This seems to be one of the causes which makes it difficult to control this plant(Fig. 6).

EMERGENCE ECOLOGY OF PERENNIAL WEEDS AND THEIR REPRODUCTION

1. Characteristics of weed sprouting

Seeds germination and vegetative propagule sprouting are governed with many factors such as dormancy, temperatures, soil moisture, light and oxygen. In general, weeds germinate or sprout irregularly when they have long and nonuniform dormancy period. *Eleocharis kuroguwai* and *Sagittaria trifolia* are the typical species.

For the sprouting of perennial paddy weeds, the minimum temperatures are about 10℃, the optimum and the maximum temperatures are 30-35℃, 40-45℃, respectively. The minimum temperatures are lower than the minimum temperature for seed germination of rice of 12-13℃. Many of gramineous and cyperaceous weeds are promoted their germination by alternative temperatures. Besides, many of weed seeds can germinate both light and dark condition, while some species of weeds such as *Scirpus juncoides* are promoted to germinate in light condition.[1]

Oxygen requirement of the tubers of perennial weeds for sprouting was generally low except for tubers of *Cyperus serotinus*, which cannot sprout if they are burried in the flooded soil as they have large oxygen requirement. In contrast with this weed, *Sagittaria pygmaea* and *Potamogeton distinctus* tend to sprout uniformly when they are put under flooding condition by ploughing and puddling. It is because that ethylene or carbon dioxide gas which are produced from the soil by flooding promotes their sprouting with endogeneous ethylene.[20]

Necessary soil moisture for their sprouting of hydrophytic weeds, such as *Sagittaria pygmaea*, *Sagittaria trifolia* and *Potamogeton distinctus*, is more than 80 percent of the maximum water capacity. However, *Cyperus serotinus* and *Eleocharis kuroguwai* can sprout even under upland soil moisture condition.

When weeds emerge from seeds, they do within one or two cm deep in soil under flooding condition; this is rather shallow compared with the depth of sprouting of vegetative propagules. They generally emerge from deeper zones of the soil except for *Cyperus serotinus* which need much oxygen.

2. Seasonal variation in emergence

Perennial weeds need more time to sprout as the temperature gets further from their optimum temperatures; especially under lower temperature conditions, it takes much time for their sprouting.

The mean cumulative temperatures of major perennial weeds from pudding to the emergence are 100-120℃ for *Cyperus serotinus* (tubers), 150℃ for *Eleocharis acicularis* (rhizomes) and *Alisma canaliculatum* (seeds), 180-200℃ for *Scirpus juncoides* (seeds), 250℃ cor *Sagittaria pygmaea* (tubers), 300℃ for *Sagittaria trifolia* (tubers) and *Potamogeton distinctus* (bulbs), 400℃ for *Eleocharis kuroguwai* (tubers).[22]

Seeds germinate in 5-12 days after puddling, but it takes about 5-25 days for vegetative propagules to emerge; it is obvious that this emergence period is variable depending upon the weed species. The tubers of *Cyperus serotinus* have no dormancy. They locate in shallow zone of the soil, so they show comparatively regular emergence. On the other hand, the emergence periods of *Sagittaria trifolia* and *Eleocharis kuroguwai* are especially longer compared with other plants (Fig. 7 and 8).[10,26]

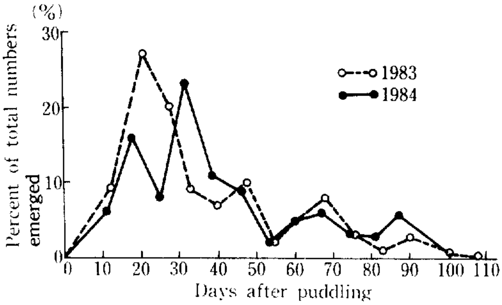


Fig. 7. Seasonal variation in emergence of *Sagittaria trifolia* (Koyama et al. 1986)
Note : Puddling, April 22 in 1983 and May 4 in 1984.

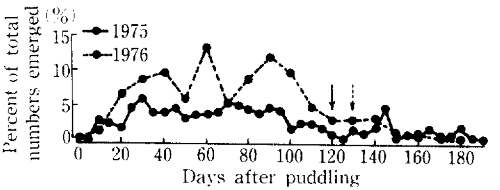


Fig. 8. Seasonal variation in emergence of *Eleocharis kuroguwai* (Yamagishi *et al.* 1978). 1) Arrows show the harvest time of rice plant 2) Total population sprouted of 75 was 421, '76 was 987.

3. **Reproduction**

Weeds reproduce changing their growth form of aerial part. It can be divided into following four types from practical point of view :

(1) Non-clonal growth type : they have no runner or rhizome and are characterized by large seed production and ease in seed propagation. *Scirpus juncoides* and *Alisma canaliculatum* are the typical ones.

(2) Rhizome type : they propagate producing rhizomes, emerge from a deep zone of the soil, and have strong propagation ability. *Scirpus planiculmis* and *Eleocharis kuroguwai* are included in this type.

(3) Prostrate type : they propagate producing runners horizontally on the soil surface or in a shallow zone of the soil, and bearing buds or roots on the nodes. They also show extremely large regenerative activity. ***Oenanthe javanica, Paspalum distichum*** **belong to this type.**

(4) Free-floating type : they are hydrophytic weeds floating on the surface or in water. Serious damage is sometimes caused by them in some limited areas. *Azolla japonica* and *Spirogyra arcla* are in this type.

Reproduction of perennial weeds affected by various kinds of cultural works, in particular, by ploughing. In general, ploughing suppress the reproduction. However, on the contrary, those weeds which propagate by runner, rhizome, and root tuber, or by long and narrow tubers with many lateral buds are promoted their reproduction by rotary tillage because the reproductive organs are cut into pieces with nodal buds. The examples are *Oenanthe javanica* and *Cyperus serotinus*.

Damage caused by these weeds is varies in reproduction type, and in amount of weed infestation. Under non-weeding condition, yield loss caused by *Cyperus serotinus* reaches 30-50%, 20-60% by *Eleocharis kuroguwai*, 15-20% by *Sagittaria pygmaea*, 15-30% by *Scirpus juncoides* and 20-50% by *Potamogeton distinctus*.

Factors which directly affect the competition between rice plant and weeds are nutrients, light, and soil moisture. In rice paddies, nutrients and light are main important factors. Especially the competition for nutrients at the early growth period results in large yield loss. The competition for nutrients prevent tillering of rice plant, causing the decrease of the number of panicles and the yield decreases. The damage on this case is most serious (Fig. 9).[10,18,26]

When weeds are controlled for a period after planting a crop, weed damages can be generally avoided by preventing the succeeding weed emergence and growth with the shading by the crop canopy. Relative light intensities at 10 to 20% are enough to suppress the emergence and growth of weeds. This period necessary for weed control is called the critical period for weeding. It varies with areas, cultivation methods and weed

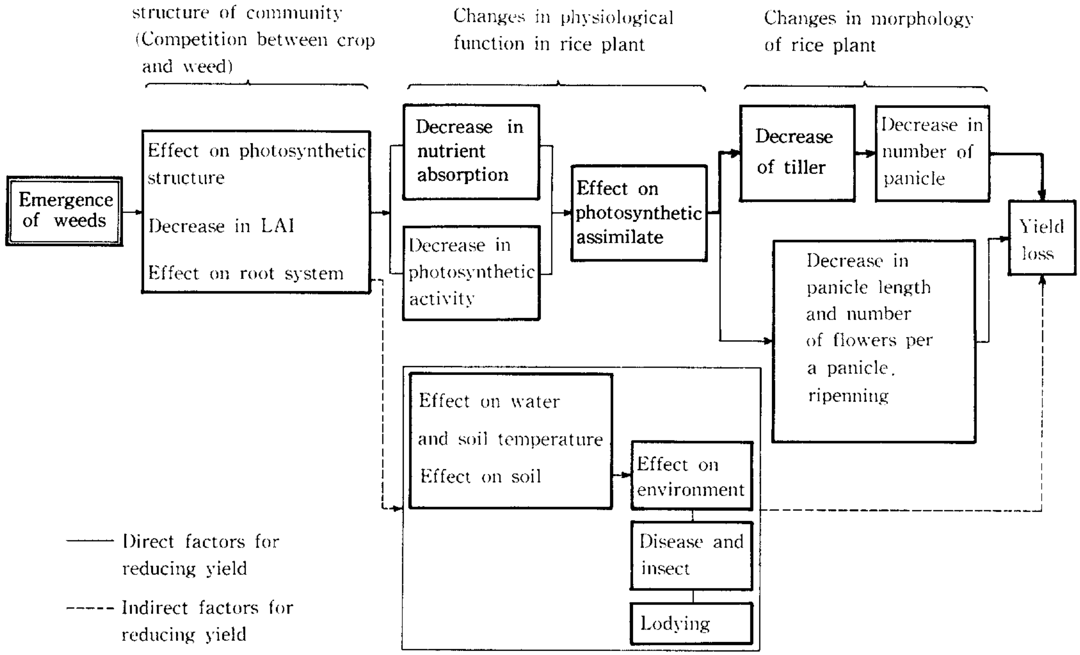


Fig. 9. Factors affecting yield loss by the emergence of weeds.

species. In transplanting with young rice seedlings, the critical period for weeding is about 50 days after transplanting in cold, or cool district, and 25-35 days in warm district. However, 60-70 days are required where some weeds with long emergence period such as *Eleocharis kuroguwai* and *Sagittaria trifolia* are infested.[10)26)]

Recently intraspecific variation of a weed, presence of the biotypes different in morphological and/or ecological characteristics in a species, is observed in *Sagittaria pygmaea*, *Cyperus serotinus* and *Scirpus juncoides*.[8,9,15)16,21,27)] The intraspecific variation is partly responsible to the difference in the damages a crop receives from weeds and in efficiency of a weed control measure.[23)]

METHODS OF WEED CONTROL

1. Cultural method

As vegetative propagules of perennial paddy weeds contain much moisture in them as stated above, they cannot survive under dry condition. Therefore, weed emergence can be extremely decreased by ploughing in fall in the area where the soil gets dry from fall to winter because the vegetative propagules on the surface of the ground die owing to dry weather, whereas, in flooded or poor drained paddies, it has little effect to kill those weeds (Table 4).[13)] In the dry condition, only ploughing can decrease 50 percent of the weed emergence for *Sagittaria pygmaea* and *Cyperus serotinus* in the next year.

The lowland-upland rotation is also effective for control of perennial weeds.[13)] This is concerned with the life span of vegetative propagules ; the life span of them of most weeds is within two or three years except for *Eleocharis kuroguwai*. Therefore they die out when the rice paddy is rotated to upland field for three years ; and they will not emerge again even if the field is rotated back again to a paddy field. But the weeds which propagate mainly by seeds like *Scirpus juncoides* have longer life span of seeds, and they are so resistant to low temperatures and dry weather that if once they invade into paddies, a long period is necessary for their control (Table 5).

Table 4. Rate of extinction (%) of tubers in relation to methods of tillage and soil water condition after tillage (Kusanagi *et al*. 1977)

Weed species	Plowing			Rotary tillage			Non-tillage		
	Flooded	Wet	Dry	Flooded	Wet	Dry	Flooded	Wet	Dry
Sagittaria pygmaea	2.7	25.0	42.4	6.6	17.3	24.0	3.9	0.4	1.9
Cyperus serotinus	0	42.0	49.5	0	35.1	37.0	0	0	0
Eleocharis kuroguwai	4.2	26.1	55.6	0	19.2	40.0	0	0	13.3

Note : 1) Determined with tubers sampled from 0-5 cm depth of soil layer.
2) Depth of tillage : About 15 cm for overturning plowing and about 10 cm for rotary tillage.
3) Time of tillage : Middle December.

2. **Chemical control by using herbicides**

Recent herbicide development is put priority in developing a compound herbicide effective both on annual and perennial weeds since the infestation by perennial weeds has spread over wide areas and the acreage of fields has increased in those infested both by annuals and perennials (Fig. 10).

Recently, one-shot application, the effective mixture for a long period with wider spectrum, is gradually being spread. With the use of this one-shot application, simple weeding system and labor-saving weed control and expected(Fig. 11). Weed control system must be designed taken the following two points into consideration : critical

Table 5. Control of paddy perennial weeds by lowland-upland rotation (Kusanagi *et al*. 1980)

Weed	Before rotation		After rotation	
	Weed infestation			
	Number of hills per m^2	Dry matter weight per m^2	Number of hills per m^2	Dry matter weight per m^2
Sagittaria pygmaea	834	38.5	0	0
Eleocharis kuroguwai	728	441.2	384	118.6
Cyperus serotinus	1,072	437.3	0	0
Sagittaria trifolia	52	129.2	0	0
Potamogeton distinctus	-	162.6	0	0
Scirpus juncoides (Seed)	42	48.2	44	6.4

Note ; The lowland-upland rotation was done by rotating a lowland to upland condition for 3 years and returning it to lowland condition again.

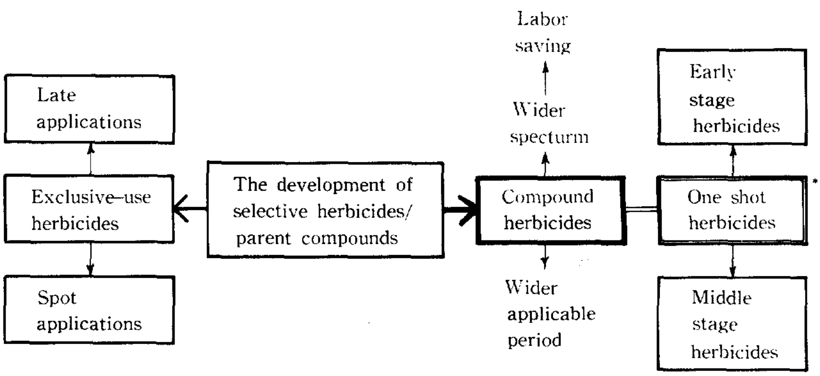


Fig. 10. Current status of herbicides development
* For those fields infested both with annual and perennial weeds

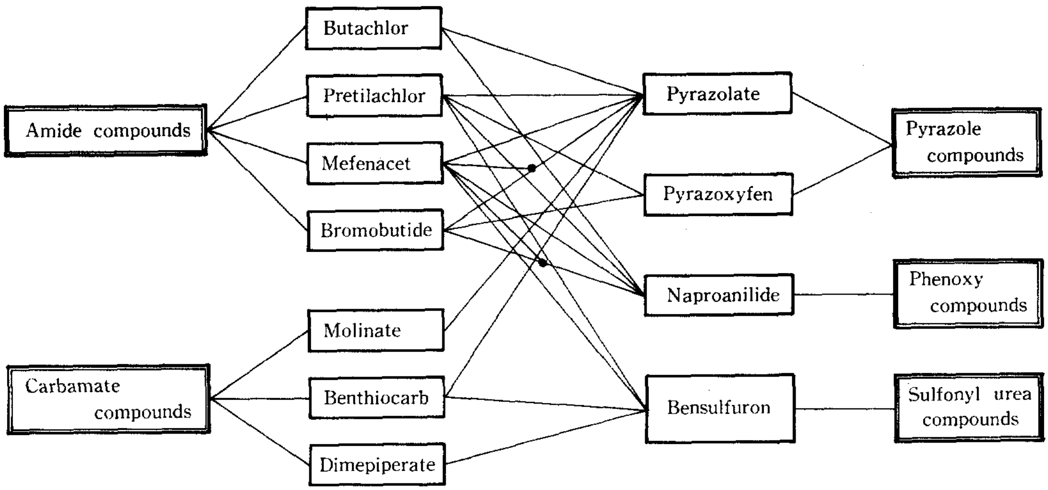


Fig. 11. Combination of major one-shot application herbicides(1987)

period for weeding after transplanting and the period of the residual efficacy of a herbicide. System treatment is especially needed for better weed control in the several cases : (1) weed emergence lasts for a long period (2) there is a extensive infestation by perennial weeds (3) the period from puddling to transplanting gets longer mainly because of edaphic factors or the competition with other agricultural work.

For controlling perennial weeds, system and spotted treatments are effective. It is not always necessary every year. The treatment at two or three year intervals is effective enough to prevent the damage by weeds, but depending on the infestation.

3. Future prospects of weed control

For the future prospects of weed control, we must avoid an excessive dependence on herbicides and reduce the total cost for weed control. In this circumstance, perennial weed control by microorganisms is promissing and such researches will be conducted in future.

Pathogenic or microorganic substances may have high selectivity on target organisms, and could be effective agent to control highly competitive and hard-to-control weeds, it seems very useful to discover some microorganisms or its metabolite which selectively control that kind of plants, for no crop plants belong to Cyperaceae.

Microorganism pesticides originated from the metabolites may have an advantage to easily decompose and leave no long-lasting residues in soils. Little adverse effects for the environment will be expected as well as the high reproduction, low cost and energy saving.

In the United States, weed control making use of pathogens has already put into practice.[14] At present, two kinds of microorganic herbicides are registerd : Devine for the control of strangler vine (*Morrenia odorata*) by *Phytophytora palmivora*, and Collego for the control of *Aeschynomene vrginica* by *Colletotrichum gloeosporiodes*. These weed species are difficult to be controlled by existing herbicides.[17,19,25]

In Japan, a pathogen which defoliate *Eleocharis kuroguwai* has been discovered and its practical use is highly expected.[21] It is also found that gibberellin, one of microorganic metabolite, has a large adverse effect on tuber formation of *Eleocharis kuroguwai* and *Sagittaria trifolia*.[2]

New technological development and productivity improvement by new cultural methods are quite important for future agriculture in Japan. Direct seeded rice and minimum tillage are started to be looked over again from the points of labor and resource savings. For more labor saving weed control, rational usage of herbicides will play an important role in the future.

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