The Succession of Noxious Weeds in Tropical Asian Rice Fields with Emphasis on Malaysian Rice Ecosystems

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Abstract

Both allogenic and autogenic successions occurred among weed communities in tropical Asian rice ecosystems. These successions were largely attributed to changes in habitat brought about by and in response to changes in crop establishment techniques, weed management and other agronomic practices of what used to be low pesticide and low fertilizer sedentary traditional farming to pesticide and inorganic fertilizer-oriented irrigated and mechanized rice farming. The resulting changes in weed community populations and species diversity were brought about principally by the shift in rice culture replacing the labour-intensive transplanting technique with direct seeding since the mid-1980s. Direct-seeded rice culture and continuous use of phenoxy herbicides then have resulted in species shift in weed community structure favouring the more competitive graminoids, viz. *Echinochloa crus-galli* complex, *E. colona, Leptochloa chinensis, Ischaemum rugosum* and *Paspalum distichum* in tropical Asia and of late weedy rice (*Oryza sativa*) in Malaysia. Being C_4 plants, these graminoids are well adapted to hot, arid and high intensity light regimes prevailing in the tropics. These species are also comparatively efficient in nitrogen and water uptake and can inflict severe yield losses on rice. The predominance of graminoids in direct-seeded rice culture since the mid-1980s, has led to inevitable changes in the pattern of herbicide use favouring the highly selective graminicides among farmers. This in turn has promoted the proliferation and recurrence of broadleaved weeds and sedges at the expense of graminoids.

Key words: allogenic, autogenic, successions, weed community, species diversity, weed management, agronomic practices, transplanting, direct seeding (DSR), phenoxy herbicides, graminicides, *Echinochloa crus-galli, E. colona, Leptochloa chinensis, Ischaemum rugosum, Oryza sativa, Paspalum distichum*

Introduction

Rice is a major food crop in the tropics. The recent emphasis on direct-seeded rice culture in the tropics especially in Asian countries is due to widespread use of herbicides in controlling weeds (De Datta and Flinn, 1986) and rising labour cost in the Philippines,Thailand and Malaysia (Ho, 1991).

In the past decade in Southeast Asia, there has been a shift in the rice production system from transplanting to direct seeding (DSR), of which wet seeding (pre-germinated seeds broadcast on puddled soil) has been the main method of rice culture in Malaysia, Thailand, Philippines, Vietnam and Sri Lanka (Moody, 1993). Meanwhile dry seeding of rice onto non-puddled soils is practiced in India, Bangladesh, Indonesia and parts of Sri Lanka (Upasena, 1980 cited in Moody, 1983).

In irrigated rice areas of Thailand, the Philippines, Sri Lanka, Malaysia, Fiji Island and Vietnam, rapid changes from transplanting to direct seeding method have been motivated *inter-alia* by the introduction of effective herbicides, development of short-culm and early maturing rice cultivars and burgeoning labour cost of transplanting (Itoh, 1991). Currently more than 90% of the irrigated rice area in Peninsular Malaysia is now direct-seeded instead of the traditional transplanting.

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Weed populations in areas free from disturbance by tillage regimes or herbicides are considered to be relatively stable, in terms of density and species diversity (Harper, 1977). However, when ecosystems are disturbed or cultivated as under most agricultural conditions, weed populations change, colonizing bare ground, a response typical of ruderal species (Groves, 1992).

Connell and Slatyer (1977) consider *inter-alia*, that contemporary ecological concept has shifted from the early Clementsian idea of a successional series of species moving inexorably towards a stable state (the *climax climatic*) incorporating at least three possible pathways. Due to the continuous nature of disturbance by cultivation, tillage operations, herbicide applications, and other agronomic practices, the appropriate model of succession for a weedy agricultural land lies "somewhere" between the tolerance model applied to secondary succession and that which Connell and Slatyer (1977) denoted as inhibition model. The former model in the absence of further disturbance depicts an old-field succession. Invariably, the net effect of agricultural operations is to maintain vegetation at an early successional stage suitably adapted to competitive ruderals.

The weed flora in a rice field is markedly influenced by the method of rice culture (Ampang-Nyarko and De Datta, 1991). Continuous rice cultivation with unchanged cultural system encourages the buildup of weeds adapted to that system. Although weed problems in rice vary from one ecosystem to another, it is widely recognized that weeds cause more damage than other pests, in particular in upland rice compared with all the other ecosystems in which rice is grown (Akobundu, 1987).

Noxious weeds in rice

Noxiousness is a measure of both the undesirability of a weed and the difficulty in controlling it (Akobundu, 1987). There are about 350 weed species in 150 genera with 60 families known to be problematic in rice (Smith, 1983). Of these, species of Poaceae are the most common with more than 80 species. Among them are *E. crus-galli, L. chinensis, I. rugosum, E. colona* and weedy rice (*Oryza sativa/O. spontanea*).

In tropical Asian countries, the moderately warm to high temperature and high humidity are conducive to year-round luxuriant weed growth. Among them are *Echinochloa crus-galli* complex, *E. colona, E. oryzicola, Leptochloa chinensis* and *I. rugosum* (Itoh, 1991 ; Ho, 1991). These weeds have become dominant and competitive in DSR in the tropics.

The advent of direct seeding and the continuous usage of phenoxy-group of herbicides and inadequate water supply, *inter-alia*, are factors perceived to be responsible for the shift in weed species dominance and diversity in rice ecosystems. *Echinochloa crus-galli* complex (*E. crus-galli* var. *crus-galli, E. crus-galli* var. *formosensis*), along with other *Echinochloa aggregates* (*E. oryzicola, E. colona, E. stagnina* and *E. picta*), *Leptochloa chinensis, Ischaemum rugosum and Paspalum distichum*, which were not so prevalent and dominant in Malaysian rice fields in the 1970s (Baki and Azmi, 1992 ; Azmi *et al*., 1993) became widespread in the 1990s. In many areas of the Philippines, *E. crus-galli* is fairly common in wet-seeded rice (Casimero *et al*., 1994). Other weeds reported to be of importance included *P. distichum, I. rugosum, M. vaginalis* and *Sphenoclea zeylanica*.

Echinochloa crus-galli, a cosmopolitan and noxious species in many tropical crops, is considered to be the major weed of rice (Holm *et al*., 1977). It has been reported as a weed in 61 countries and 36 different crops (Barret, 1983). The world distribution of *E. crus-galli* ranges from 50° N to 40° S latitude (Fig. 1) (Holm *et al*., 1986). The ecological requirements of *E. crus-galli* are very similar to those of rice and certain varieties of the former are very difficult to distinguish from one another in the early stages of growth (Yabuno, 1966). Barnyardgrass is a C_4 plant which grows very well under wet conditions (Maun and Barret, 1986). In addition, C_4 weeds display higher net photosynthetic rates, water and N use efficiency than do the C_3 plants of which rice is one under all light regimes (Ampong-Nyako and De Datta, 1989). Under shade, therefore, C_4 weeds have a competitive advantage over rice.

Echinochloa crus-galli complex consist of three subspecies namely *E. crus-galli* var. *crus-galli, E. crus-galli* var. *formosensis* and *E. crus-galli* var. *praticola* (Kim, 1994). Both *E. crus-galli* complex and *E. oryzicola* resemble the rice plant and their growth is restricted to rice fields. These species are important weeds in Southeast and East Asia.

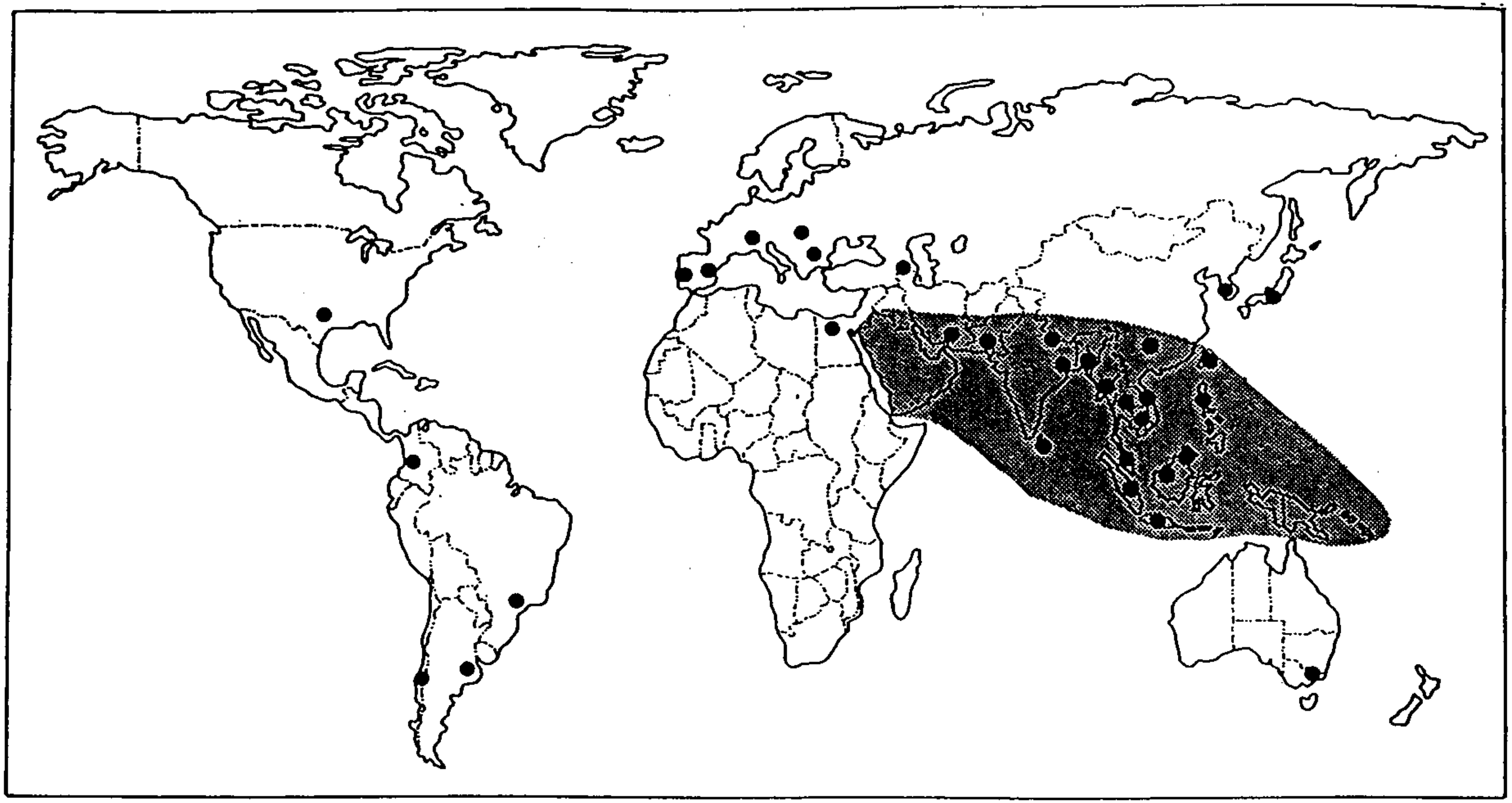

Fig. 1 *Echinochloa curs-galli* (L.) Beauv. across the world and tropical Asian region where it has been reported as a weed in rice (adapted from Holm *et al.*, 1977)

L. chinensis, a true native of tropical Asia (Soerjani, 1987), is a common weed of rice in Malaysia, Indonesia, Pakistan, Sri Lanka, Burma, Thailand, Laos, Cambodia and Vietnam. In the Muda area, Malaysia, *L. chinensis* is rated as one of the most noxious weeds in DSR (Itoh, 1991). Like *E. crus-galli*, it is a C_4 species and is highly adapted to hot, arid and high intesity light conditions (Ampang-Nyarko and De Datta, 1991). In growth strategy, the weed is positioned closer to the r end of the r-K continuum (Radosevich and Holt, 1984). Extreme r-selection leads to a short-lived plant (usually less than one year), occupying open habitats and showing an early stage of succession. A large proportion of biomass of r-strategists is allocated to reproduction and the population is regulated by physical factors.

Another important grass weed in tropical rice areas is *Ischaemum rugosum*. It was reported to be a major weed of partially irrigated and rainfed lowland rice in Thailand, Sri Lanka, Philippines, Malaysia and India (Lubigan and Moody, 1989 ; Holm *et al*., 1977 ; Azmi *et al*., 1993). It is an annual grass and a native of tropical Asia (Holm *et al*., 1977). It is easily recognized by its spiral awns and by the prominent transverse ridges on the lower glume of the spikelet.

Echinochloa colona is also an important weed species in rice in the Philippines and India (Holm *et al*., 1977). It is an annual grass and a native of India. The weed is an excellent competitor and if the rice crop is badly managed the crop may be forced out by this weedy plant. It has a prostrate growth habit in early seedling stages.

An emerging threat in DSR in tropical Asia is weedy rice. Weedy rice can be defined as rice plants which occur spontaneously as weeds within or around rice fields (Moody, 1994). Moody (1994) reported that weedy forms of rice occurred in Malaysia, Philippines and Vietnam. In Malaysia weedy rice is locally known as *padi angin*. *Padi angin*, with many morphological variants, shows a high degree of deciduousness before being harvested (Wahab and Suhaimi, 1990). Baki (unpublished) recognized at least 80 variants of weedy rice species in Malaysia. Many theories have been put forward on the origin of weedy rice. Moody (1994) lists 6 possible ways in which weedy rice can evolve, *viz* ; (a) outcrossing with wild or shattering rice, (b) segregants of a heterogeneous cultivar, (c) degeneration of the cultivar due to continuous use, (d) seed mixtures, (e) volunteers from the previous crop and (f) mutation. Similar arguments have been proposed by Abdullah *et al*. (1994).

The seeds of noxious weeds often enter rice fields with crop seeds (Holm *et al*., 1977). They may be transferred from neighbouring fields through farm machineries and on the feet, fur, feathers and skin of rodents, birds and larger animals, including human.

Weed succession and distribution patterns in rice fields are dynamic in nature and are governed by spatio-temporal elements, and the agronomic practices being employed. As such, species dominance and their patterns of distribution varied considerably. A few species, could claim the status of ubiquity in rice areas of Peninsular Malaysia in 1980, i. e. *Monochoria vaginalis, Ludwigia adscendens, Fimbristylis miliacea, Scirpus grossus, Limnocharis flava, Leersia hexandra, Cyperus haspans and L. hyssopifolia* (Baki and Md. Khir, 1983). With the dissemination of direct seeding in the 1990s, there was a dramatic shift in the weed flora in the rice fields. Azmi *et al*. (1993), reported that *E. crus-galli* was the most dominant weed in DSR. Other important weeds in rice included *F. miliacea, Limnocharis flava and M. vaginalis*. Comparison of shift in weed dominance after about 10 years in Malaysian rice fields is shown in Tables 1 and 2.

Ho (1991) recorded a meaningful shift in species dominance among rice weeds in the Muda granary, arguably brought about by the change in rice culture from the dominantly transplanting rice culture in 1979 to direct seeding in 1989 (Table 3). Rapid rise of *E. crus-galli* as the most dominant weed species in DSR in Kemubu rice area, Malaysia was found to be related to the adoption of DSR by Azmi (1994).

In the 1989 season only transplanted rice was adopted in the granary. However, 50.4% of the area was subjected to DSR in the 1991 season and 79.6% in the 1993 season. Table 4 lists the major weeds of rice in Southeast Asia (Waterhouse, 1991).

Factors influencing weed succession in rice ecosystem

1. Crop establishment technique

In a review on the changes in the weed flora associated with reduced tillage systems, Froud-Williams *et al*. (1981) cited several studies where the distribution of perennial monocot and dicot species increased

Table 1 Comparison of ranking of the dominance of 15 species dominance of major-rice field weeds in Peninsular Malaysia in 1980 and 1990 based on importance value indices

Weed species	Ranking	
	1983[a]	1993[b]
Monochoria vaginalis	1	4
Fimbristylis miliacea	2	2
Ludwigia repens	3	—
Leersia hexandra	4	—
Cyperus haspan	5	—
Limnocharis flava	6	3
Scirpus grossus	7	13
Eleocharis variegata	8	—
Ludwigia hyssopifolia	9	6
Salvinia molesta	10	—
Scirpus juncoides	11	—
Isahne globosa	12	—
Utricularia aurea	13	12
Scirpus mucronatus	14	—
Lindernia pedunculata	15	—
Echinochloa crus-galli	—	1
Echinochloa colona	—	7
Leptochloa chinensis	—	5
Sphenoclea zeylanica	—	14
Marsilea crenata	—	10
Cyperus iria	—	8
Cyperus difformis	—	15
Najas graminea	—	11
Sagittaria guyanensis	—	9

— minor weeds
[a] Baki and Md. Khir (1983)
[b] Azmi *et al*. (1993)

in the absence of tillage. They considered that perennial monocots constituted the greatest threat to adoption of reduced tillage systems. Furthermore, reduced tillage tends the favour rhizome and stolon-bearing perennials over annuals. Similar findings of more diverse populations of perennial weeds were reported in reduced tillage regimes (Buhler *et al*., 1994). In his work, Pollard & Cussans (1976) noted the high prevalence of perennials in non-tillage compared to systems that included pre-plant tillage. Studies in the impact of agronomic practices on weed communities carried out by Derksen *et al*. (1993, 1994) did not reveal any increase in the association of perennial and annual grasses with zero tillage. They also observed that changes in weed communities were markedly influenced by time and space rather than tillage systems operating, indicating fluctuational rather than directional or consistent changes in community composition. Sagar (1970) gave a schematic representation of the factors that may control the size and to a certain extent species succession in an agricultural area.

Weed populations in rice are influenced by the crop establishment method. Baki and Azmi (1992) have reported that more broadleaved weeds grow in association with transplanted rice while more grassy weeds with wet-seeded rice. Moody and Drost (1981) reported that weed problems will be less prevalent when wet-seeded or transplanted rice is grown as the first crop than dry-seeded rice. Pablico *et al*. (1994) reported that water seeding changed the species composition of the major weeds from grasses and sedges

Table 2 Weed shift from transplanting to direct seeding method in Peninsular Malaysia

Irrigated transplanting 1970s	Extensive direct seeding 1980s~1990s	Intensive direct seeding in future
Grasses		
Isachne globosa	*Echinochloa crus-galli*	*L. chinensis*
Leersia hexandra	*Leptochloa chinensis*	*E. oryzicola*
	O. sativa (weedy rice)	*O. sativa* (weedy rice/volunteer seedings)
Broadleaved weeds		
Limnocharis flava	*L. flava*	*S. guyanensis**
Monochoria vaginalis	*M. vaginalis*	*M. vaginalis***
	Sagittaria guyanensis	*Spenoclea zeylanica***
Sedges		
Scirpus grossus	*Cyperus iria*	*F. miliacea***
		*C. iria***

* Herbicide-resistant species (2,4-D)
** Herbicide-resistant biotypes (2,4-D)

Table 3 Changes in weed flora and dominance from transplanting to direct seeding in the Muda area (1979-1989) modified from (Ho, 1991)

Diversity indicator and % direct-seeded area	Season					
	2/79	1/82	1/84	2/84	1/87	1/89
No. of species	21	34	42	45	50	57
No. of genera	18	18	30	30	38	44
No. of families	13	14	19	17	22	28
% direct-seeded area	0.2	20.7	53.0	24.0	98.9	81.7
Dominant weed species*	M.vag	M.vag	F.mil	E.cru	E.cru	E.cru
	L.hys	L.hys	M.vag	S.gro	E.col	L.chi
	F.mil	F.mil	E.cru	L.hys	L.chi	F.mil
	C.dif	L.hex	S.gro	P.amp	S.gro	M.cre
	L.fla	S.gro	M.cre	L.chi	F.mil	M.vag

*M.vag – *Monochoria vaginalis*; S.gro – *Scirpus grossus*; L.hys – *Ludwigia hyssopifolia*; E.cru – *Echinochloa crus-galli*; F.mil – *Fimbristylis miliacea*; M.cre – *Marsilea crenata*; C.dif – *Cyperus difformis*; P.amp – *Panicum amplexicaule*; L.fla – *Limnocharis flava*; L.chi – *Leptochloa chinensis*; L.hex – *Leersia hexandra*; E.col – *Echinochloa colona*

to broadleaved weeds which accounted for 78-91% of the weed flora by weight. Baki (1995) employing canonical discriminant analysis in his extensive studies on the influence of tillage regimes and weeding practices of weed communities in direct-seeded rice in Malaysia reported that spatio-temporal changes in weed community in the rice granary of Seberang Perai, if any, were erratic and fluctuational and were dependent on crop season and influenced by weeding practices and inherent differences in species composition between plots. As pointed by Derksen *et al*. (1994), *inter-alia*, periodic weed assessments in long-term studies which were a point in time samplings, may produce findings which are not truly representative of community response to production practices. While changes in diversity status and species composition in weed communities did occur in Seberang Prai fields among weeded and non-weeded plots, no consistent changes in species association have been recorded solely due to tillage regimes. It was obvious that meaningful changes in a weed community both in species diversity and species composition *vis-a-vis* tillage regimes and other agrotechnical practices require a longer period of experimentation and are likely to be

Table 4 The distribution and importance of the most important rice weeds in South Asia (modified from Waterhouse, 1993)

Scientific name	MYAN	THAI	LAOS	CAMB	VIET	MSIA	SING	BRUN	INDO	PHIL
Aeschynomene indica	•	+	•	++	•	•			•	++
Altemanthera sessilis	+	+	•	•	+	+	++		•	++
Borreria latifolia		•				+++	++		++	+
Brachiaria mutica		•	•		•	++	+		+	
Cleome viscosa	+	•		•	•	+	++		•	
Commelina benghalensis	++	+++			+	•			++	++
Commelina diffusa	•	++	•		•	•	++		++	++
Cynodon dactylon	++	++	+	+	+++	++	++		+++	++
Cyperus brevifolius	•	•	•	•	•	+	+			++
Cyperus compactus						+	+		•	++
Cyperus compressus	+	+	•	•	•	++	++	+	+	++
Cyperus difformis	+	+	+	++	+++	+++	+		++	+++
Cyperus iria	++	++	++	++	+++	+++	+		•	++
Cyperus kyllingia		•	•	•	++	++	+++	•	+++	++
Cyperus rotundus	+++	+++	++	++	+++	++			•	+++
Digitaria sanguinalis					•					+++
Digitaria violescens	•	•	•	•			++	++	•	++
Echinochloa crus-galli	•	+++	+	++	+++	+++	++		+++	+++
Echinochloa glabrescens		•	•	++	+++	+++		+	+++	+++
Echinochloa oryzoides	•	•			•	•			•	++
Eclipta prostrata	+	++	•	•		•	++			+++
Eichhornia crassipes	++	+++	++	++	++	+++	•		+	++
Eleusine indica	++	++	++	++	+	+++	+++	++	++	+++
Fimbristylis dichotoma	++	+	++		•	+	++		+++	+
Fimbristylis globulosa	•	•	•	•	++	++	++		+++	++
Fimbristylis miliacea	+++	+	+	+++	•	++	++		•	•
Hellotropium indicum	+	+	•	•	+	+++	•		+++	++
Hydrilla verticillata	•	++	•	•	•	•	+	•	•	++
Hymenachne actigluma						+	++		+	+
Ischaemum muticum	+	•	•	•	•	++	++	•		+
Ischaemum rugosum	•	+	+	+	+	+++	+	+	++	++
Leersia hexandra		+	+	+	++	++	+	+	•	+
Leptochloa chinensis	+++					+++			++	++
Limnocharis flava		+	•	•	•	++				
Lindernia crustacea	+				•	++	+	•	•	
Ludwigia adscendens	+++	+	•	•	•	++	++		•	•
Ludwigia hyssopifolia	+	++	•	•	•	++			•	++
Ludwigia octovalvis	+	•	•	•	•	•	•		•	+
Marsilea minuta	•	+	+	+	+	+++	+		+	++
Marsilea quadrifolia	+	•	•	•	+++			++	++	++
Melochia corchorifolia	++	•		•	•	+++			•	+
Mimosa invisa	++	+++	++	+	++	+++	++		•	+
Mimosa pigra	+++	+	•	•	+	++	++	++	++	+++
Mimosa pudica					+	++	+++		++	
Monochoria hastata	++	++	+++	+++	+	++	+	+++	+++	++
Monochoria vaginalis		•			++	•	++	•	+	

(Table 4 continned)

(Table 4 continned)

Scientific name	MYAN	THAI	LAOS	CAMB	VIET	MSIA	SING	BRUN	INDO	PHIL
Oldenlandia corymbosa	++	+	•	•	•	+++	++		+++	+++
Oryza rufipogon	•	•			•	++			•	+
Paspalum distichum	•	•	•	•	•	+			+	•
Paspalum scrobiculatum		+	+	+	•	•	++		+++	++
Pennisetum purpureum	+	++	++	++	+	++	+	+	•	+
Pistia stratiotes	•	•	•	•	++	+	•		+	+
Rotala indica	+	++	+		++	+			+	++
Rottboellia	•	•	•	•	+	++			•	+
cochinchinensis		++	+	+	•	+	+		+++	+++
Sagittaria guyanensis					+	+++			•	
Salvinia cucullata	++	•	•	•		•	+		•	
Salvinia molesta	++	•	•	•	+	+++			+	++
Scirpus grossus	•	•	•	•	•	+++			•	+
Scirpus juncoides					•	++			+	•
Scirpus maritimus						•			•	+++
Scirpus supinus					•	++				+
Scleria sumatrensis	•	•				++	+			

+++, very widespread and very important; ++, widespread and important; +, important locally; •, present, but not important

dependent upon species, time and environmental variables.

The non-weeded plots registered higher overall densities ranging from 80.9 ± 7.3 to 88.0 ± 6.2 plants/m^2 than the weeded plots with 26.9 ± 6.2 to 30.4 ± 10.6 plants/m^2. These apparent differences in density ratings of weed species between plots subjected to weeding and non-weeding practices were compounded by changes in diversity status and species composition of weed communities in plots subjected to different tillage regimes and times. Marked differences were recorded in the relative density, relative frequency, relative dominance, relative abundance and important value indices between species (Table 5). A total of 29 species of weeds belonging to 14 families were recorded in the 1991-1992 seasons depicting a typical weed flora of rice granary of Seberang Prai (Azmi *et al*., 1992, 1993). Intriguingly, no *Portulaca oleracea* was observed in 1993. Weed communities were dominated by ten species in the order of relative abundance or importance value; *Monocharia vaginalis* > *Echinochloa crus-galli* > *Fimbristylis miliacea* > *Limnocharis flava* > *Bacopa rotundifolia* > *Cyperus iria* > *Sagitaria guyanensis* > *C. haspans* > *Paspalum distichum* > *Rotola rosea*.

It appears that factors other than tillage systems may have contributed to the weed compositional differences. This is exemplified by the significant differences between tillage regimes T_3 and T_4 in 1992 and 1993 but not in 1991 or T_2 and T_4 in 1991 but not in 1992 and 1993. In the Seberang Prai granary of Peninsular Malaysia, it is possible that changes in environmental conditions in the field may have contributed to these differences. In fact, 1991 was a relatively drier year compared to 1992 and 1993. Derksen *et al*. (1993, 1994) among others observed that changes in weed communities were influenced more by location and year than by tillage systems, indicating fluctuational rather than directional or consistent changes in community composition. Furthermore, such changes may have been influenced by the relative timing of management practices.

Weed species association and affinity with tillage regime could be assessed for the experimental year when species compositional differences were recorded (Table 5) by comparing vector length and direction. Most of the species present (Table 5) were not particularly associated with a specific tillage regime, except for ten major species (Fig. 2). Differences in association, wherever observed varied with time and to a certain extent, species.

High incidences of *E. crus-galli* populations were associated with plots subjected to minimum tillage

Table 5 Weed species recorded in experimental plots at MARDI Research Station, Bertam, Seberang Prai in 1991-1993 (Baki, 1995)

No.	Species	Relative density			Relative frequency			Relative dominance			Relative abundance			Importance value		
		1991	1992	1993	1991	1992	1993	1991	1992	1993	1991	1992	1993	1991	1992	1993
1.	*Utricularia aurea* Lour.	0.62	0.55	0.49	0.42	0.33	0.30	0.72	0.64	0.55	0.52	0.44	0.40	1.76	1.52	1.34
2.	*Najas graminea* (non Del) Ridl.	0.45	0.33	0.40	0.53	0.42	0.44	0.52	0.47	0.39	0.49	0.38	0.42	1.23	1.22	1.50
3.	*Lemna minor*L.	4.96	4.36	5.44	5.51	4.98	5.67	5.68	5.82	6.33	5.24	4.67	5.54	16.15	15.16	17.41
4.	*Sagittaria guyanensis* HBK	2.28	1.90	2.31	2.96	3.18	3.40	2.61	2.84	2.32	2.62	2.54	2.86	7.85	7.69	8.03
5.	*Limnocharis flava* (L.) Buchenau	9.24	9.26	9.78	7.75	8.18	8.66	6.96	6.82	6.21	8.50	8.72	9.22	23.95	24.26	24.65
6.	*Spirodela polyrhiza* (L.) Schlaid.	0.32	0.27	0.17	0.28	0.30	0.29	0.42	0.39	0.36	0.30	0.29	0.23	1.02	0.96	0.82
7.	*Rotala rosea* (Poir.) C.D. Cook	3.87	4.72	4.87	3.21	3.74	3.86	3.55	3.50	3.19	3.77	4.23	4.37	10.63	11.96	11.92
8.	*Marsilea crenata* Presl.	1.07	0.98	0.92	1.12	1.48	1.98	1.96	1.88	1.72	1.10	1.23	1.45	4.15	4.34	4.62
9.	*Ludwigia adscendens* (L.) Hara	0.78	0.68	0.65	1.11	1.08	0.96	1.12	1.06	0.98	0.95	0.88	0.81	3.01	2.82	2.59
10.	*L. hyssopifolia* (G. Don) Exell	2.11	2.08	2.72	3.54	3.42	3.34	2.90	2.88	3.44	2.83	2.75	3.03	8.55	8.38	9.50
11.	*Poriulaca oleracea* L.	0.33	0.27	0.00	0.27	0.19	0.00	0.42	0.48	0.00	0.30	0.28	0.00	1.02	0.94	0.00
12.	*Monochoria vaginalis* (Burm.f.) Presl.	14.11	14.39	12.06	10.87	9.65	9.77	14.33	14.40	14.34	12.49	12.63	10.92	39.31	38.44	36.17
13.	*Lindernia ciliata* (Colsm.) Pennel	0.27	0.18	0.00	0.37	0.33	0.00	0.42	0.39	0.00	0.32	0.26	0.00	1.06	0.90	0.00
14.	*Bacopa rotundifolia* (Michx.) Wettst.	7.11	6.98	6.92	8.25	8.11	8.62	8.36	8.11	8.37	7.68	7.55	7.77	23.72	23.20	23.91
15.	*Limnophila aromatica* (Lamk.) Marr.	0.44	0.32	0.27	0.53	0.67	0.64	0.62	0.79	0.64	0.49	0.50	0.46	1.59	1.78	1.55
16.	*Sphenoclea zeylanica* Gaertn.	1.38	2.33	2.28	2.46	2.44	2.40	1.72	1.78	1.65	1.92	2.39	2.34	5.56	6.55	6.33
17.	*Echinochloa crus-galli* (L.) Beuv.	12.00	10.72	10.38	7.87	7.08	7.24	10.37	9.24	9.81	9.94	8.90	8.81	30.24	27.04	27.43
18.	*E. colona* (L.) Link	1.00	1.18	1.31	2.10	3.15	3.37	2.48	3.32	3.58	1.55	2.17	2.34	5.58	7.65	8.26
19.	*Hymenochne acutigluma* (Stend.) Gilliane	1.62	1.58	1.47	1.87	1.92	1.89	2.08	2.02	2.96	1.75	1.75	1.68	5.57	5.52	6.32
20.	*Leptochloa chinensis* (L.) Nees	1.89	1.90	1.74	1.55	1.62	1.60	1.98	2.00	1.89	1.72	1.76	1.67	5.42	5.52	5.23
21.	*Paspalum distichum* Swartz	2.97	2.82	2.45	5.28	5.32	5.92	4.42	4.59	4.11	4.13	4.07	4.19	12.67	12.73	12.48
22.	*Panicum repens* L.	1.12	1.32	1.48	2.57	2.72	2.61	2.11	2.48	2.51	1.85	2.02	2.05	5.80	6.52	7.60
23.	*Cyperus haspans* L.	4.28	5.92	6.88	4.90	4.94	4.42	2.96	2.87	2.74	4.59	5.43	5.65	12.14	13.73	14.04
24.	*C. babakan* Stend	2.01	1.49	2.33	2.33	2.11	2.28	2.23	2.42	2.43	2.17	1.80	2.31	6.57	6.02	7.04
25.	*C. difformis* L.	2.18	4.15	4.10	3.76	3.58	3.59	2.42	2.13	1.89	2.97	3.87	3.85	8.36	9.86	9.58
26.	*C. iria* L.	7.66	6.66	6.24	6.29	6.12	5.82	8.06	8.47	8.29	6.98	6.39	6.03	22.01	21.25	20.35
27.	*Fimbristylis miliacea* (L.) Vahl.	8.68	8.22	8.25	5.98	5.75	5.41	4.00	3.62	3.47	7.33	6.99	6.83	18.66	17.59	17.13
28.	*Scirpus gross* I. f	1.57	2.47	2.44	3.34	3.01	2.82	2.41	2.63	2.80	2.46	2.74	2.63	7.32	8.11	8.06
29.	*S. juncoides* Roxb.	1.04	1.97	1.83	2.98	2.70	2.73	2.17	1.96	1.93	2.01	2.34	2.28	6.19	6.63	6.49

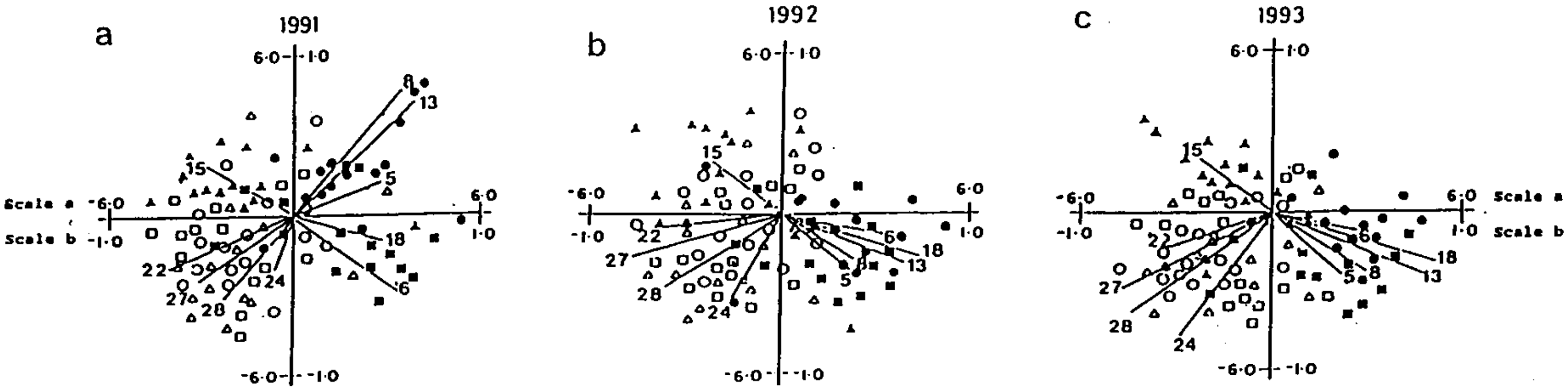

Fig. 2 Canonical discriminant analysis ordination diagram of treatment clusters for zero tillage (●), minimal tillage (■), two rounds (△)*, three rounds (▲), four rounds (○) and five rounds of conventional tillage (□) regimes (scale a) and biplot scaling of dominant weed species vectors indicating treatment associations at Bertam in 1991-1993 in plots where no hand weeding was performed at 15-30 DAS. Symbols represent individual tratment plots and their position is located based on relative species compsoition. Species association with treatment can be ascertained by the direction of the vectors. Vector length indicates the relative strength of association between weed species and the respective tillage regime. Vectors labeled for dominant species which have attributed to community discrimination and species identity are given in Table 2. x-axis= canonical function 1, y-axis= canonical function 2 (after Baki, 1995)

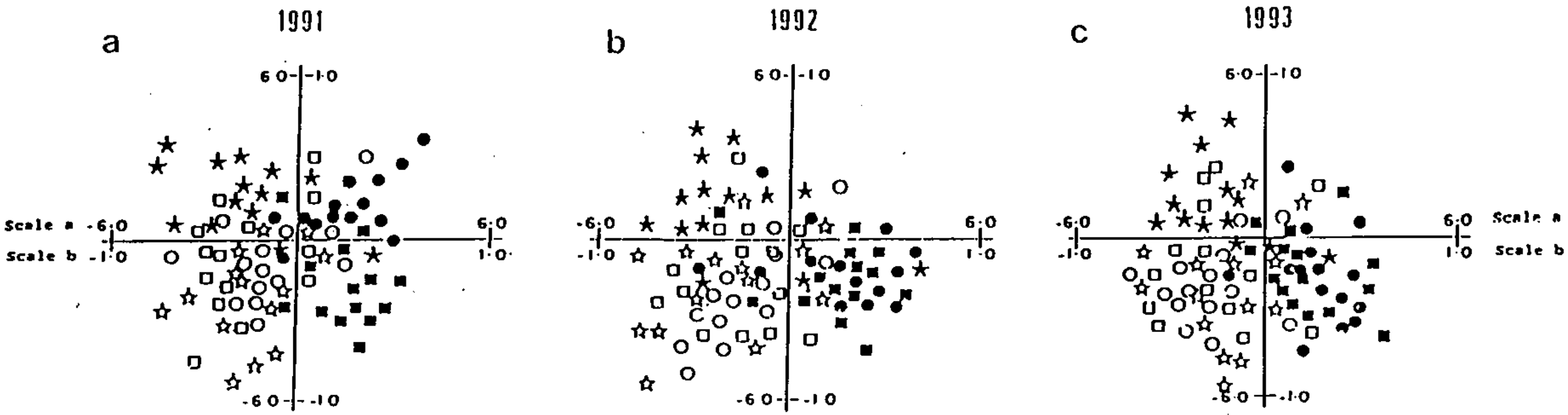

Fig. 3 Canonical discriminant analysis ordination diagram of treatment clusters of for zero tillage (●), minimal tillage (■), two rounds (☆), three rounds (☆), four rounds (○) and five rounds of conventional tillage (□) regimes (scale a) and biplot scalling of dominant weed species vectors indicationg treatment associations at Bertam in 1991-1993 in plots where no hand weeding was performed at 15-30 DAS. Symbols represent individual treatment plots and their position is located based on relative species composition. Species association with treatment can be ascertained by the direction of the vectors. Vector length indicates the relative strength of association between weed species and the respective tillage regime. Vectors labeled for dominant species which have been attributed to community discrimination and species identity are given in Table 2. x-axis= canonical function 1, y-axis= canonical function 2 (after Baki, 1995)

regime especially in plots not subjected to hand weeding (Fig. 2). These were the case for all seasons of 1991-1993, based on vector lengths. *Echinochloa crus-galli* was a major weed problem in many rice-growing countries and Malaysia is no exception (Azmi *et al*., 1993).

The previous argument of increased annual grass species in reduced tillage (Froud-Williams *et al*., 1981) was based on the difficulty in controlling them in cereals especially monocultural crops (Pollard and Cussans, 1976). Similar findings have been reported by Derksen *et al*. (1994) for *Avena fatua and Setaria viridis.*

In the case of *E. crus-galli* reduced tillage enables the weed to proliferate and produce many seeds without any disturbance after emergence, especially in non-weeded plots. Similar patterns were observed in weeded plots, although the populations were understandably lower (Fig. 3).

Another problematic graminoid species in the Malaysian rice fields is *Paspalum distichum*. Together with the sedges *C. haspans, C. iria and Fimbristylis miliacea*, this graminoid was strongly associated with four or five rounds of conventional tillage throughout the experimental seasons of 1991-1993. Arguably, conventional tillage regimes did not appear to reduce the populations of these weed species (Fig. 3).

For unknown reasons, *Bacopa rotundifolia* has a reasonably strong association with three rounds of conventional tillage irrespective of weeding regimes (Figs. 2 and 3) for all seasons. *Rotala rosea, L. flava, S. guyanensis and M. vaginalis*, showed a strong association with zer or minimum tillage (Figs. 2 and 3) in the 1992-1993 seasons. In 1991, *L. flava, R. rosea and M. vaginalis* exhibited a strong association with plots subjected to zero tillage. This apparent "shift in association" between broadleaved weeds and tillage regime may be explained by the inherent seed banks retained in the soils from the previous growing seasons and posed problems in subsequent seasons when no control measures were implemented.

Baki (1995) suggested that species groupings into broadleaved, sedges and grasses responded in similar ways to agronomic practices according to their groups. The notable examples were *B. rotundifolia* which was strongly associated with three rounds of conventional tillage while other broadleaved weeds such as *R. rosea, S. guyanensis, L. flava* and *M. vaginalis* had a close affinity to zero-and minimum tillage regimes (Figs. 2 and 3). Such similar responses were not observed with the exception of sedge species within the group. Derksen *et al*. (1994) recorded different responses among species of the same groupings with different tillage regimes. Further studies are needed to elucidate the underlying agroecological attributes that determine the association of species with tillage systems.

2. Change in water management

Inadequate water control contributes to the increase in weed populations. This phenomenon is related to exposure of the soil to air allowing noxious weeds especially *E. crus-galli* to develop secondary roots (Ampong-Nyarko and De Datta, 1991). As a result, water seeding of rice is practiced in India, Sri Lanka, Malaysia and Thailand. Pregerminated rice is broadcast directly onto the flooded field. The rice, which is seeded at a depth of 7-10 cm, sinks to the soil, germinates and emerges from the water. The field remains flooded at a depth of 7-10 cm until a few weeks before maturity. This cultural method is used to suppress *E. crus-galli.*

3. Control methods

Weed control methods may affect the weed species growing in association with rice (De Datta, 1977; Janiya and Moody, 1989). Hand weeding is impractical in broadcast-seeded rice because it is difficult to distinguish young grassy weeds and rice plants and rice plants may be destroyed in the process. Therefore, herbicides are considered to be the only practical way of weed control in DSR. When the same herbicides are used continuously in rice without rotation, weeds that tolerate those herbicides could colonize the site. The build-up of populations of a certain weed species after the continuous use of an herbicide can be considered in two possible ways; first, the weed species is inherently very resistant to the herbicide and the elimination of its competitors favours its predominance; second, the weed species has gradually acquired resistance to the herbicide through continued absorption of the herbicide at sublethal concentrations or through the build-up of resistant strains of a normally susceptible population (Mercado, 1979). For example, molinate was used to control *E. crus-galli* but enhanced the infestation of *L. chinensis, I. rugosum* and *E. oryzicola* in Malaysia (Ho, 1991; Azmi and Mashhor, 1994). In the Philippines, *E.*

glabrescens (=*E. crus-galli* var. *formosensis*) was dominant in the unweeded and herbicide-treated fields while *M. vaginalis* was dominant in the hand-weeded fields (Mercado, 1979; Janiya and Moody, 1989).

In irrigated areas where herbicides have been used for annual weed control, *E. crus-galli* and *M. vaginalis* have become minor weeds and *Scirpus maritimus* has become increasingly dominant (De Datta, 1977). In rainfed areas, *Paspalum distichum* and *Cynodon dactylon* have become dominant (Mercado, 1979). It has been argued that in the Muda granary of Malaysia, the continuous usage of phenoxy herbicides since the 1960s and 1970s has favoured the proliferation of graminoids at the expense of broadleaved weeds especially (Table 2) (Ho, 1991). The 38-fold increase in the use of molinate since 1980 has contributed to the substantial increase in the proliferation of grasses, especially the *E. crus-galli* aggregates in the granary. Baki (unpublished data) argued that the substantial recurrence of broadleaved weeds and sedges in the granary of Tanjung Karang in the 1990s, compared with the 1970s and 1980s, arguably was attributed to the continuous use of graminicides since the last decade by farmers in their effort to suppress weedy graminoid infestation. However, the recent work by Habibah, Baki and Abd. Munir (1995) and Zaharuddin, Baki and Abd. Munir (1995) did not reveal any meaningful shift in species dominance in weed communities of the Sungei Burong and sawah Sempadan granaries of Tanjung Karang, Malaysia since the report published by Azmi *et al*. (1992).

Conclusion

Succession or shift of weed species is known to occur in continuously DSR fields in response to tillage practices, techniques of crop establishment, weed control practices and other changes in habitat. The shift of weed species from broadleaved weeds and sedges in transplanting method to noxious graminoids in DSR has been observed in tropical Asia where herbicides have been used extensively. This has been particularly evident in the Philippines, Malaysia, Thailand and is expected to increase in Indonesia and Vietnam with increasing popularity and importance of DSR. The reasons for the increase in noxious weeds are as follows: continuous use of a particular herbicide, decreased use of manual weeding, practice of minimum tillage, saturated conditions during crop establishment in DSR, the use of short-term cultivars and increased use of fertilizers. Invariably, weed successions in the Asian rice fields can be allogenic or autogenic in nature. The former is driven by forces outside the rice agroecosystem. These forces include changes in the amount and duration of available water (either through irrigation or rainfall) and agronomic practices (tillage regimes, methods of rice culture, herbicide regimes and application protocols). The over-reliance by farmers on cheap and readily available phenoxy herbicides in the 1970s and early part of the 1980s contributed to the proliferation and spread of hard-to-control graminoids like *E. crus-galli, L. chinensis* and *I. rugosum*, and of late, weedy rice (*O. sativa*/*O. spontanea*) in many rice fields of the Asian tropics. Conversely, the preferential adherence by farmers to graminicides in the 1980s and thereafter to control problematic graminoids promoted yet another cycle of recurrence and prevalence of noxious broadleaved weeds and sedges like *S. zeylanica, F. milliacea*, etc. If intensive weed control is continued for several years without interruption, the number of weed species can decrease and species diversity can be reduced (Menges, 1987). On the other hand, the high weed seed populations in the seed banks associated with prolific seed production, dormancy and longevity insulate weed populations from changes. This is especially true for many weed species in the rice fields of the Asian tropics. Autogenic succession, as the name implies, is a succession from within the system itself. In the Asian tropics, inter- and intra-specific competition among neighbouring rice weeds does occur resulting in the displacement of the less competitive species by the competitive ones. In this context, competitive graminoids like *E. crus-galli* with *phalanx* growth habits will have better chances of preventing the invasion of other competitors for space with a similar habitat than those with guerilla growth habits. Furthermore, changes in the habitat may accelerate species displacement by one another.

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Discussion

Mukhopadhyaya, S. (India): The transition from rice transplanting culture to rice seeding culture which is observed in many countries of East and Southeast Asia unlike in West Asia requires a very effective weed management system. In the case of transplanting, water management including the presence of standing water reduces the emergence of weeds as rice growth and weed growth occur at different times unlike in direct seeding culture. Moreover the weed composition is different between transplanting culture and direct seeding culture.

Itoh, K. (Japan): 1. When I visited KADA, Kembu on the Pacific coast of Peninsular Malaysia in 1991, I could not find *Echinochloa crus-galli* in the paddy fields. However presently the weed grows abundantly. How many years or paddy cropping seasons are required to observe a severe infestation of *E. crus-galli* ? 2. If farmers switch back to transplanting from direct seeding culture, will the incidence of *E. crus-galli* decrease ?

Answer: 1. After 3 to 4 seasons of rice seeding culture, grassy weeds such as *E. crus-galli* become a problem. The control of this particular weed is easy through the use of herbicides. We are concerned about the weeds that are tolerant of herbicides, such as *Echinochloa colona* or *Leptochloa chinensis*. 2. The switch to transplanting may enable to control grassy weeds due to the presence of stasnding water. However it is difficult to revert to transplanting due to the shortage of labour.