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ECOLOGICAL ASPECTS OF WEED FLORA IN AN IRRIGATED RICE FIELD ECOSYSTEM AT BATHALAGODA IN SRI LANKA

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Abstract: This study was carried out to document some ecological aspects of weeds in an irrigated rice field ecosystem in Bathalagoda, Sri Lanka. The study was conducted from November 1995 to August 1997 in two rice fields which differed in weed management practices. A total of 89 vascular plant species of rice-weeds belonging to 21 families, 31 genera of algae and three genera of macrofungi were recorded from the two rice fields surveyed. Among the dicotyledonous weeds recorded, one species (*Elatine triandra* Schkuhr.) is a new record for Sri Lanka. Of the weed flora recorded from the rice field ecosystem, 45 species were mesophytes, 41 species were hygrophytes, while three species were hydrophytes. The species composition of the weed flora was highest in the rice field bunds (82 species), while the rice field proper harboured 41 weed species, and 24 weed species occurred in the ditch habitat. In both rice fields, the temporal pattern of variation of weed species richness was similar. The weed species richness on the bunds differed according to the surface on which they occurred, and exhibited a clear spatial variation. The study also reflects the impacts of different weed management practices on the species diversity of weed flora in a rice field ecosystem.

Key Words: Biodiversity, rice fields, species richness, weed

INTRODUCTION

The rice field ecosystem harbours a rich composition of primary producers, which can be broadly grouped into two categories: the macrophytes and the microphytes. Besides the rice plant, the macrophytes include other rooted higher plants, which consist mainly of grasses, sedges and broad-leaved plants. These are generally referred to as weeds, as they compete with the rice plants for growth requirements such as space, nutrients and sunlight.[9] The microphytes include the various types of algae and fungi. The weed communities occur in three different habitat types found in the rice field ecosystem: the field proper, the bund (levee) and the ditch (water supply canal) habitats. Each of these habitats contains a distinct weed community comprising several aquatic, wetland and dryland weeds.[5] The rice field proper, which is the major habitat in the rice field ecosystem, remains under flooded conditions for a major period of a single rice cultivation cycle. The aquatic condition provides an extremely stable habitat for weeds resistant to excess water stress [22] and for various groups of algae, which together constitute the photosynthetic aquatic

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biomass (PAB) in rice fields. When the fields are drained prior to the harvesting of rice, dry conditions prevail, at which time terrestrial weeds colonise the field and become more conspicuous. Ditch habitats in the rice field ecosystem remain flooded during most parts of the year and many submerged, floating-leaved and free floating aquatic weeds are characteristic of these habitats. In contrast to the field proper and ditch habitats, the bunds remain under non-flooded, relatively dry conditions. Hence, the weed communities in the bunds consist mainly of terrestrial plants.[5]

Many ecological factors and crop production practices influence the species composition and abundance of the weed flora in the rice field ecosystem.[18] Ecological factors which affect rice field weeds are mainly climatic and edaphic factors, including hydrology, soil type and moisture regime of rice fields, air and soil temperatures, and the composition of the seed populations in the soil. The cultivation practices which affect riceland weed communities include land preparation, method of crop establishment, crop rotation, fertilisation, method of weed control and the type of rice cultivars grown.[14,18]

Based on a survey of literature on rice field weeds reported from major rice growing countries, Moody[13] has documented more than 1800 weed species occurring in the rice field ecosystems of Asia and South-East Asia alone. Species of Poaceae (grasses) are the most common, followed by Cyperaceae (sedges) and other broad-leaved families respectively. The barnyard grass (*Echinochloa crus-galli* (L.) Beauv is considered to be the most troublesome weed of rice in the world, followed by *E. colonum* (L.) Link.[18] Other rice field weeds of global importance include: grasses - *Eleusine indica*, *Ischaemum rugosum*, sedges - *Cyperus difformis*, *Cyperus rotundus*, *Cyperus iria*, *Fimbristylis miliaceae*, broad-leaved - *Monochoria vaginalis* and *Sphenochlea zeylanica*.[18] Several previous studies on the weed flora of rice fields in Sri Lanka highlight the rich diversity of weed species growing in the rice field agro-ecosystem. Velmurugu[20] reported that there are about 70-80 common rice field weed species in Sri Lanka. Weerakoon and Gunewardena[21] recorded 134 weed species belonging to 32 families from several rice fields in the three major climatic zones of Sri Lanka. Amerasinghe[10] has recorded rice weeds in minor tank rice fields of the north-central dry zone of Sri Lanka. Chandrasena[4,5] has studied the floristic composition and abundance of rice field weeds in major rice growing districts in the low-country wet zone of Sri Lanka. Chandrasena[6] has also surveyed the rice weeds in the Kurunegala District - a major rice growing area in the intermediate zone of Sri Lanka. Seneviratne *et al.*[17] studied the fallow vegetation in rice fields of the lowland dry zone of Sri Lanka, where 19 species belonging to 10 families were recorded as fallow vegetation. A provisional list of weeds found in arable soils by Ameratunge[3] includes many species of major rice weeds. Based on most of the above surveys, Moody[13] has listed approximately 340 weeds recorded from rice fields in Sri Lanka.

Specific objectives of the study on weed flora of rice fields

The available literature on the rice field weed flora in Sri Lanka shows that most studies are related to the distribution and abundance of rice weeds, while information pertaining to their seasonal colonisation and succession in a rice field is scanty. The ecology of the weed flora in the rice field bunds has also not been adequately documented. Therefore, this study was carried out to meet the following specific objectives:

I To identify and document the weed flora (microphytes and macrophytes) in a rice field, their distribution and abundance in the field proper and bund habitats, and their succession during the rice cultivation cycle.

II To determine the temporal and spatial variation in the distribution and abundance of weeds in the field bunds, using qualitative diversity indices.

III To determine the temporal species richness of weeds in two selected rice fields with different weed management practices and observe the effects of weed management practices on the species richness of weeds.

METHODS AND MATERIALS

Study sites & period of study

The study was carried out in two rice fields at Bathalagoda, in the Kurunegala district, located in the Intermediate Zone of Sri Lanka, 7°30′N, 80°280′E, 100 m a.s.l. Each rice field was approximately 0.4 ha (1 acre) in extent and the two fields were approximately 2 km apart. Both fields were irrigated with water supplied by the neighbouring Bathalagoda tank. One rice field ('research field') was managed by the Rice Research and Development Institute (RRDI) at Bathalagoda, for the purpose of producing seed paddy under standard Integrated Pest Management (IPM) practices recommended by the Department of Agriculture. The other rice field ('farmer field') was maintained by a private farmer who cultivated rice on a commercial scale. Each field consisted of several plots (field proper - 'liyadde'), surrounded by bunds (levees). The two rice fields differed in weed management practices. Weed management practices were more intense in the research field, with application of herbicides, manual weeding, and slashing of field bunds both partially and intensively. In the farmer field, weeds in the field proper were removed manually, without the use of herbicides, while the bunds were slashed partially. Field sampling of the rice fields began in November 1995 and continued till August 1997, encompassing four consecutive rice cultivation cycles in both fields. Sampling was carried out at fortnightly intervals throughout the above study period.

Collection, preservation and identification of the weed flora in the rice field: During the four cycles, weeds (macrophytes and microphytes) growing in the field proper, bunds and the water inlet (ditch) in the two rice fields were collected at fortnightly intervals for preparation of voucher specimens. The weeds, after being chemically treated with 70% alcohol, were placed in a plant press and left in a plant drier for 24-36 h. They were then mounted on herbarium sheets. Samples of microflora in water and top soil of the two rice fields were collected using a standard dipper, during the aquatic phase of each cycle. These were observed under a binocular stereo microscope and sorted into different groups. Algae were preserved and stored in 5% formalin. The microphytes were identified upto the generic level, using keys of Abeywickrema[1] and Abeywickrema *et al.*[2] The macrophytic weeds were identified up to species level, using the keys of Chandrasena,[7] Soerjani *et al*[19] and Dassanayake and Fosberg.[8] The voucher specimens were also compared with herbarium specimens at the Department of Botany, University of Peradeniya and at the National Herbarium of the Royal Botanical Gardens at Peradeniya. The provisional identifications were confirmed by an authority at the National Herbarium.

Sampling of rice field weeds: During the *Maha* 1995 and *Yala* 1996 cycles, the weed species richness in the rice field proper and the bunds in the research field and the farmer field were monitored at fortnightly intervals. On each sampling day, the number of weed species in four random plots (1m^2 each) in the middle of each *liyadde* and at four random 1m length portions along the field bunds were counted. Weed management practices carried out were also noted.

A bund aligned across the flow of water consisted of three surfaces; a flat upper surface, a shallow lateral surface on the upper side of the bund and a deep angular lateral surface on the lower side of the bund. A bund aligned parallel to the flow of water consisted only of a flat surface and two shallow lateral surfaces on either side. As a clear difference in the composition of weed flora was observed on the three different surfaces in the first bund category, the bund weed flora in the research field was further evaluated during the *Maha* 1996 and *Yala* 1997 cycles. Three replicate sites (1.5 m in length) of this bund category were selected for monitoring, commencing from the field preparation stage at which time the bunds are completely cleared of weeds. The breadth of each bund surface monitored was measured. The soil moisture content (%) of each surface was measured on three occasions, at early, mid and later stages of the crop cycle, by taking random soil core samples. The weed cover at the three sampling sites in the bund were left unslashed until the completion of each rice cultivation cycle.

During both cycles studied, the occurrence and relative abundance of each weed species was also determined about 95 days after transplanting (DAT), when each bund surface was fully covered with weeds. A strip quadrat (100cm x 25cm) was placed on each of the bund surfaces of the three study bunds and the relative abundance of each weed species was scored on a scale of 1-5 as follows:1 = Rare; 2 =

Occasional; 3 = Moderate; 4 = Common; 5 = Abundant. The scores 1,2,3,4 and 5 correspond to a visual cover estimation of <10%, 11-25%, 26-40%, 41-70% and >71% respectively of the strip quadrat for each species.

Data analyses: Using the qualitative data on the total number of weed species in the field proper and bunds during the *Maha* 1995 and *Yala* 1996 cycles, the temporal variation of the species richness of macrophytes in the field proper and bunds was represented graphically using mean species richness (N_0) values. The mean species richness of weeds in the field proper and the bunds in the research and farmer fields was statistically compared using the GLM procedure of the SAS system.

Using the qualitative data on the occurrence of different weed species in the three bund surfaces during the *Maha* 1996 and *Yala* 1997 cycles, the β-(differentiation) diversity of weeds in each bund surface, and the degree of association or similarity of pairs of bund surfaces based on weed composition, were determined using Whittaker's measure (β_w) and Jaccard index (C_j) respectively, as described in Magurran;[12]

β diversity: $\beta_w = S\alpha - 1$, where S = total number of species, and α = mean species richness.

Species similarity: $C_j = j/(a+b-j)$, where j = the number of species found in both sites, a = number of species in site A, and b = number of species in site B.

The above two indices are widely used to express the variation in species composition, using qualitative species data.[12]

RESULTS

Floristic composition of rice field weeds

A total of 89 species of rice-weeds (macrophytes) belonging to 21 families, 31 genera of microphytes (algae, under 4 phyla) and three genera of macrofungi were recorded from the two rice fields surveyed. Appendix 1 provides a comprehensive list of the species of rice weeds recorded, with information on their occurrence in major habitats of the rice field ecosystem , their life-cycle and life forms. Appendix 2 gives a list of algae and macrofungi recorded. Of the total weed species recorded, 42 were monocotyledons (in five families), 45 were dicotyledons (in 14 families), while two species were pteridophytes (under two families). The monocotyledons were dominated by grasses (Family: Poaceae - 21 species), followed by sedges (Cyperaceae - 14 species). Among the dicotyledons recorded, the Family Asteraceae had the highest number of species (11 species) followed by Scrophulariaceae (07 species). Among the dicotyledonous weeds recorded, one species (*Elatine triandra* Schkuhr.) is a new record for Sri Lanka.

A high proportion (65 %) of the weed species recorded were annuals. The species composition of the weed flora was highest in the rice field bunds (82 species), where 36 species were exclusive to it and 27 of these exclusive species were dicotyledons (Table 1). The rice field proper harboured 41 weed species with five species confined to this habitat. Twenty four weed species occurred in the ditch (water inflow canal), with none being exclusive to it. Of the weeds that occurred in the rice field proper, *Echinochloa colonum*, *Isachne globosa*, *Ischaemum rugosum*, *Cyperus haspan*, *Fimbristylis miliaceae* , *Marsilia quadrifolia*, and *Elatine triandra* were the most abundant species during all the rice cultivation cycles. Of the species recorded from bunds, the dominant species included the monocotyledons *Echinochloa colonum*, *Panicum repens*, *Cyperus rotundus*, *Fimbristylis miliaceae*, *Cyperus iria*, and *Commelina diffusa*, and the dicotyledons *Ageratum conyzoides* and *Lindernia rotundifolia* and the fern *Marsilia quadrifolia*. Several species of cosmopolitan, terrestrial dicotyledonous weed species occurred in the field bunds and these included *Ageratum conyzoides*, *Vernonia cinerea*, *Euphorbia hirta*, *Mimosa pudica*, *Urena lobata*, *Sida rhombifolia*, *Emilia sonchifolia*, *Tridax procumbens* and *Mikania cordata*. Species of *Axonopus* and *Commelina* showed a dense and widespread growth along the ditch habitat.

Of the weed flora recorded from the rice field ecosystem , 45 species (50.5 %) were mesophytes (species which grow well in dryland conditions), 41 species (46 %) were hygrophytes (species which grow well in water saturated conditions) while three species (3.5 %) were hydrophytes (weeds growing well in submerged conditions). Compared to the weeds in the field proper and ditch habitats, the weeds on the bunds exhibited a wide variety of life-forms, which included erect, ascending, tufted, tillering, stoloniferous, rhizomatous, creeping, prostrate and climbing forms.

The algae included blue-green algae (BGA, Phylum Cyanophyta - 8 genera), green algae (Chlorophyta - filamentous forms - 1 genus; flagellated forms - 3 genera; non-flagellated, non-motile desmids - 15 genera), Euglenophytes - 2 genera, and diatoms (Bacillariophyta - 2 genera). The abundant genera of algae included: cyanophytes - *Oscillatoria* and *Aphanothece*; chlorophytes - *Spirogyra*, *Closterium*, *Micrasterias*, *Pleurotaenium* and *Pediastrum*; euglenophytes - *Euglena*; Diatoms - *Navicula*. The macrofungi were recorded from the fallow fields with decaying vegetation, during the rainy seasons.

Seasonal colonisation and succession of weed flora

Succession in the field proper: The general pattern of colonisation and succession of flora in the rice field ecosystem was similar during each cycle. At the beginning of each rice cultivation cycle, practices associated with the preparation of fields (ploughing, puddling and tillage) resulted in the complete destruction of the fallow vegetation in the field proper and bunds. Within 2-3 days of flooding the fields, rich populations of unicellular green algae, dominated by phytoflagellates such as

Euglena, *Phacus*, *Chlamydomonas*, *Volvox* and *Gonium* and diatoms such as *Navicula* appeared in the floodwater surface as green mats. These were soon followed (3-5 days after flooding) by epibenthic filamentous algae, including *Spirogyra* and *Oscillatoria* which formed dense mats on the floodwater surface during midday. Solitary and colonial desmids and non-mucilaginous cyanophytes also occurred at the same time. *Monochoria vaginalis* and *Marsilia quadrifolia* were the first aquatic macrophytes to appear within the first week of transplanting. These were followed by monocot weeds such as *Ischaemum rugosum*, *I. timorense*, *Isachne globosa*, *Cyperus haspan*, *Fimbristylis miliaceae* and *Echinochloa* spp. and the dicot species *Sphenoclea zeylanica* which emerged during the 2nd and 3rd weeks after transplanting. Other monocots such as *Cyperus iria*, *C. difformis* and dicots such as *Ludwigia* spp., and *Elatine triandra* appeared within 3-4 weeks of transplanting. A considerable change in the composition and abundance of floodwater microflora was clearly evident towards the mid aquatic phase (about 7 weeks after transplanting), where the filamentous algae became absent or scarce, while dense colonies of mucilaginous blue-green-algae consisting of *Aphanothece* spp. and *Aphanocapsa* spp. appeared.

Table 1: Distribution of the weed flora in the different habitats of the rice field.
(m = Monocotyledons; d = Dicotyledons; p = Pteridophytes)
(Values indicate the total number of species)

Location	Bund	Field	Ditch	Total
Bund only	36 (10m,26d)	-	-	36(10m,26d)
Field only	-	5 (2m,2d,1p)	-	5 (2m,2d,1p)
Ditch only	-	-	-	-
Field and Bund	24 (14m,10d)	24 (14m,10d)	-	24 (14m,10d)
Bund and Ditch	12 (8m,4d)	-	12 (8m,4d)	12 (8m,4d)
Field and Ditch	-	2 (2m)	2 (2m)	2 (2m)
Field, Bund & Ditch	10 (6m,3d,1p)	10 (6m,3d,1p)	10 (6m,3d,1p)	10 (6m,3d,1p)
Total Species	82 (38m,43d,1p)	41 (24m,15d,2p)	24 (16m,7d,1p)	89 (42m,45d,2p)

When the fields were drained during the mature stage of the crop, hygrophytic weeds such as *Monochoria vaginalis* and *Elatine triandra* as well as hydrophytic weeds such as *Lindernia* spp., *Ludwigia* spp., *Cyperus haspan C. iria*, *C. difformis*, *Echinochloa* spp., and *Ischaemum* spp., started to die off gradually. Mesophytic weeds in the field bunds started to invade the drying fields. After the crop was harvested, mesophytic grasses (*Panicum repens*, *Cyanodon dactylon*), sedges (*Cyperus rotundus*, *Kyllinga* spp.) and dicots (*Eclipta prostrata*, *Sphaeranthus indicus*, *Desmodium* spp., *Euphorbia* spp.) which were previously inhibited by the floodwater, started to germinate and rapidly colonise the dry fallow fields.

Succession on bunds: The first species to appear on the bunds following clean weeding were *Marsilia quadrifolia* and sedges including *Cyperus* spp. and *Fimbristylis miliaceae*, within a week of transplanting. About two weeks after transplanting, numerous species of hygrophytic and mesophytic monocot and dicot weeds started to emerge on the bund surfaces. All the bund surfaces were completely covered by weeds at approximately 12 weeks after transplanting. At this time, the flat bund surface was dominated by grasses (*Cyanodon dactylon*, *Eragrostis unioloides* and *Panicum repens*), sedges (*Cyperus rotundus*, *Pycreus polystachyos*) and *Commelina* spp. The shallow bund surface was dominated by *Fimbristylis miliaceae*, while the deep bund surface was dominated by many species of mesophytic dicots which were mainly erect forms.

Effect of weed management practices on the richness and succession of weed species

The seasonal succession of weeds in relation to agronomic practices was clearly evident when the temporal variation of the mean weed species richness in the field proper (spp./m^2) and bunds (spp./m) was considered in the research and farmer rice fields, during two consecutive cycles, *Maha* 1995 and *Yala* 1996 (Fig. 1). In both fields, the temporal pattern of variation of weed species richness was similar during the two consecutive cycles. The mean weed species richness in the field proper and bunds showed a gradual increase after transplanting, and reached a stable level at approximately 90 days after transplanting. Draining of fields at the mature stage of the crop and subsequent drying of fields resulted in a slight decline in the weed species richness in the field proper, but increased during the fallow period. Weed species richness in the bund habitat started to decline after the mature stage of the crop, when most annual weeds entered the senescent phase. The weed species richness in the field proper and bunds was affected by weed control practices. The weed species richness declined with the application of herbicides (in the research field only), manual weeding (both in the research and farmer fields), and slashing of weeds in the bunds. Fertiliser inputs resulted in a rapid proliferation of individual weed populations in the field proper and on the shallow surface of the bunds.

Based on the data gathered during the *Maha* 1995 and *Yala* 1996 cycles, the mean weed species richness in the field proper of the farmer field was significantly higher ($P<0.05$) than that of the research field (Table 2). However, the mean weed species richness in the bunds of the two fields was not significantly different ($P>0.05$). In both rice fields, the mean weed species richness in the field proper as well as on the field bunds between the two consecutive cycles (*Maha* 1995 and *Yala* 1996) was not significantly different ($P>0.05$).

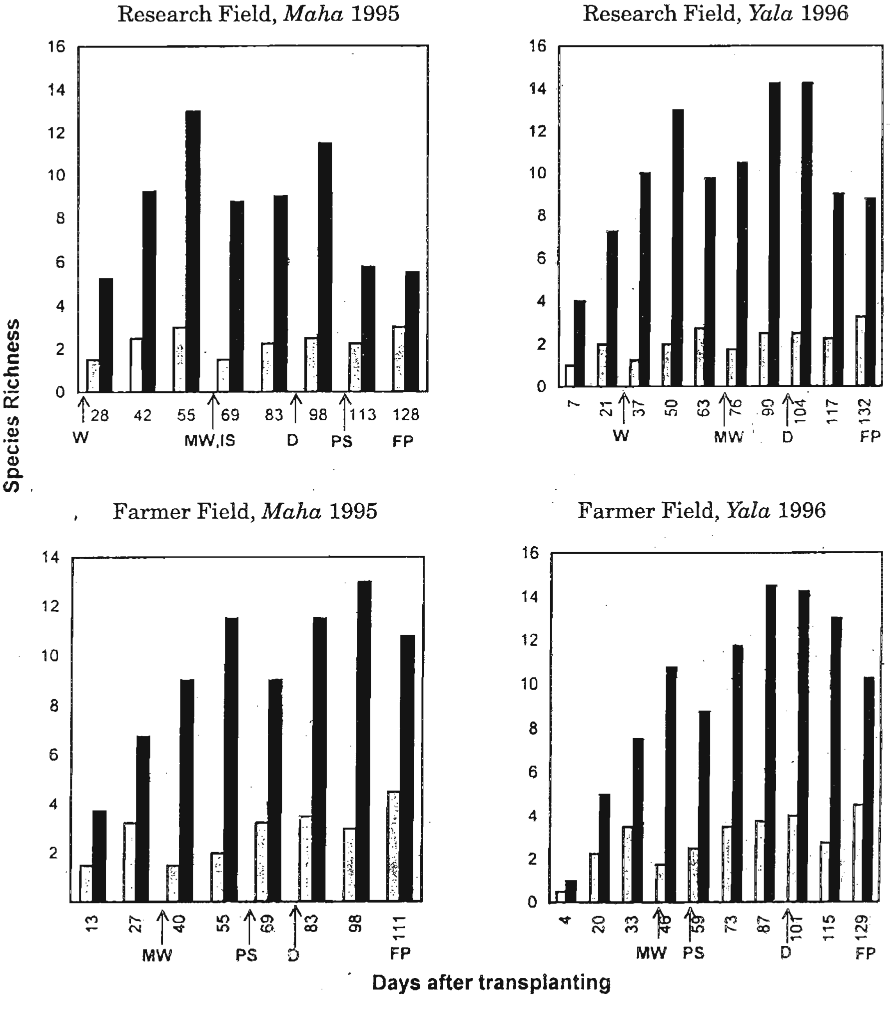

Figure 1: Temporal variation of weed species richness in the field proper (grey) and field bunds (black) of the research field and farmer field, during the *Maha* 1995 and *Yala* 1996 cycles.

W- Weedicide application; MW- Manual weeding; PS - Partial slashing IS- Intense slashing; D- Draining of fields; FP- Fallow period

Distribution of weeds in the three bund surface types

The flat, shallow and deep surfaces of a bund differed in breadth, soil moisture content (%) and light regime (Table 3). The shallow bund surface had the highest soil moisture content and the lowest breadth, while the effect of shading by the growing rice canopy was also high, resulting in a low light regime compared to the shallow and deep bund surfaces.

Table 2: Mean weed species richness in the field proper and bund habitats in the two fields, during the *Maha* 1995 (October 1995 - February 1996) and *Yala* 1996 (April - August 1996) cycles.

Site	Field proper (spp./m^2)	Field bunds (spp./m)
Research field	**2.20 B**	**9.20 A**
Maha 1995	2.31 a	8.50 a
Yala 1996	2.12 a	9.02 a
Farmer field	**2.86 A**	**9.55 A**
Maha 1995	2.81 a	9.40 a
Yala 1996	2.90 a	9,67 a

Duncan grouping: Means (vertically) with the same letter (upper case: between fields, lower case: between cycles) are not significantly different

Table 3: Physical features associated with the three bund surface types.

Feature	Shallow surface	Flat surface	Deep surface
Breadth (m)	0.25 ±0.03	0.32 ± 0.05	0.95 ± 0.09
Soil moisture content (%)			
Aquatic phase:	48.4 ± 6.97	29.6 ± 6.57	24.8 ± 3.47
Dry phase:	18±1.38	12.5±1.58	10.9±2.48
Light regime	Low	moderate	high

The weed species that were present in the three bund surface types during *Maha* 1996 and *Yala* 1997 seasons at 90 days after transplanting, and their relative abundance (score) are presented in Appendix 3. Weed species varied in occurrence and commonness in the three bund surface types and the general appearance of weeds in the three bund surfaces is shown in Fig. 2. Moreover, based on the presence of different weed species in the three bund surface types, 3 distinct distribution categories were identified (Table 4). The first category included 15 weed species (species Nos.1-15 in Appendix 3) which were distributed in all three bund types, and included 11 monocots and 4 dicots. The second category included weed species that occurred in any two bund surface types only (11 species, Nos. 16-26 in Appendix 3). The 3rd category included weed species that were restricted to one bund type only (15 species, Nos.27-41 in Appendix 3). Interestingly, species in this last category were found only in the shallow and deep bund surfaces, and surprisingly 11 of the species were restricted to the deep bund surface.

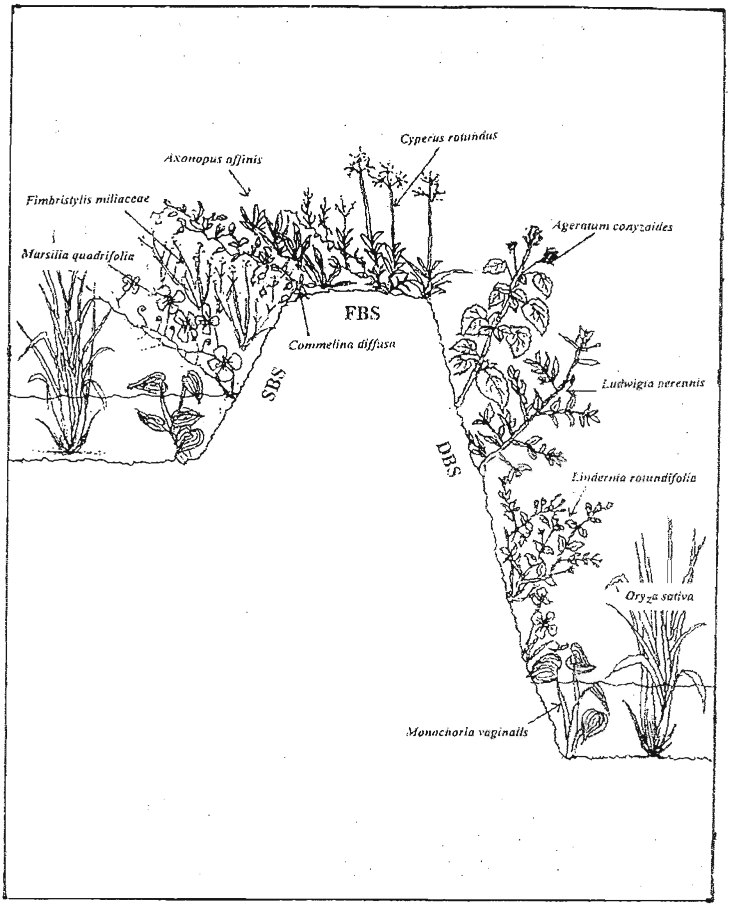

Figure 2: A diagram showing the general appearance and distribution of weeds on the different bund surface types in a rice field (FBS - Flat surface; SBF - Shallow surface; DBS - Deep surface).

The β-diversity of weed species occurring in the three bund surfaces during the *Maha* 1996 and *Yala* 1997 cycles was assessed at three spatial levels, viz., between similar surface types, between different surfaces and between bunds as a whole (Table 5). As indicated in Table 5, the β-diversity values increased from the 1st level of assessment (between similar surfaces) to the 3rd level of assessment (among bunds), while the temporal variation at each of the above levels was approximately similar during the two consecutive cycles. The β-diversity in the shallow bund surfaces showed a higher variation compared to those in the flat and deep bund surfaces. At the next level, β-diversity of the shallow and deep bund surfaces showed the highest variation. The variation of weed species among the bunds (3rd level) was slightly higher during the *Maha* 1996 cycle, than that during the *Yala* 1997 cycle. Based on similarity coefficients (Table 6), the weed communities in the shallow and deep bund surfaces were the least similar, while those in the flat and shallow bund surfaces were the most similar. The general trend as well as the values of the similarity coefficients was relatively similar during the two consecutive cycles.

Table 4 : Distribution of weed species in the three bund surfaces
(Values indicate the total number of species)

Category	Flat	Shallow	Deep	Total
1. Common to all bund surfaces	15	15	15	15
2. Common to any two surfaces				
a. Flat and shallow bunds	3	3	-	3
b. Shallow and deep bunds	-	4	4	4
c. Flat and deep bunds	4	-	4	4
3. Restricted to one surface only				
a. Flat bund only	-	-	-	-
b. Shallow bund only	-	4	-	4
c. Deep bund only	-	-	11	11
Total	22	26	34	41

Table 5: Spatial and temporal variation of weed species occurring in the three bund surface types during the *Maha* 1996 and *Yala* 1997 cycles, at 90 DAT, based on β-diversity values using Whittaker's measure (β_w).

Cycle	*Maha* 1996			*Yala* 1997		
Source of Variation	S	α	β_w	S	α	β_w
1. Between similar surfaces						
Flat surface	19	12.66	0.50	19	11.33	0.67
Shallow surface	23	10.66	1.15	22	12.33	0.78
Deep surface	34	20.66	0.64	30	17.66	0.69
2. Between different surfaces						
Flat vs. Shallow	26	11.66	1.23	26	11.83	1.19
Shallow vs. Deep	40	15.66	1.55	36	15.66	1.40
Flat vs. Deep	36	16.66	1.16	33	14.50	1.27
3. Among bunds	41	14.66	1.79	36	13.77	1.61

(S = total no. of species; α = average no. of species)

Table 6: Similarity among the three bund surface types based on weed composition (Similarity coefficients using Jaccard index- C_j), during the *Maha* 1996 and *Yala* 1997 cycles, at 90 DAT).

Weed composition in bunds	*Maha* 1996	*Yala* 1997
Weed species common to FB & SB	16	16
Similarity Coefficient (Cj)	0.61	0.61
Weed species common to FB & DB	17	16
Similarity Coefficient (Cj)	0.47	0.48
Weed species common to SB & DB	17	16
Similarity Coefficient (Cj)	0.42	0.44

FB: Flat bund; SB: Shallow bund; DB: Deep bund.

DISCUSSION

The changing ecological conditions associated with the rice field ecosystem enables a rich weed flora to colonise the rice fields and complete their life cycle during a single rice cultivation season. During the early stages of a rice cycle, the flooded rice fields are dominated by a rich composition of microflora and wetland macrophytes, while dryland weeds replace wetland weeds during the later dry stages, including the fallow period. These events of seasonal colonisation and succession of rice field flora occur in a regular manner during successive rice cultivation cycles.

The seasonal succession of microflora in the flooded rice fields observed during this study was similar to those documented by previous workers.[11,15] Similar to the observations made by Weerakone and Gunawardena,[21] Poaceae and Cyperaceae constituted the major component of the macrophytic flora in this study. The abundant macrophytic weeds recorded during the present study from a rice field in the intermediate zone of Sri Lanka, and previous records of rice weeds from the wet zone[5] and dry zone of Sri Lanka (Amarasinghe[10]), indicate that the composition of the most abundant weeds is quite similar in rice fields throughout the island. Of the most abundant macrophytic weeds recorded during the present study, *Fimbristylis miliaceae*, *Isachne globosa* and *Cyperus haspan* were previously documented as the most serious rice field weeds throughout Sri Lanka,[21] while *Ischaemum rugosum* was previously recorded as the most dominant weed in the Kurunegala district.[6] Of the weeds recorded from the bunds, although *Paspalum commersonii* and *Cyperus pilosus* were previously recorded to be among the commonest monocotyledonous weeds found in the wet zone of Sri Lanka,[4,5] these two species were found to be occasional species during the present study. The cosmopolitan dicots recorded in the field bunds during this study had been previously documented by Chandrasena[6] as well, from rice fields throughout the Kurunegala district, and were considered as opportunistic species which have invaded the rice agroecosystem. The dicotyledonous weed species (*Elatine triandra*) recorded for the first time in Sri Lanka has previously been documented as a common rice field weed in Indonesia.[19]

The significant differences in the mean species richness of weeds in the research and farmer fields could be attributed to the differences in weed management and water management practices associated with the two fields. In the research field, weeds in the field proper were removed manually and chemically (with a herbicide), and the supply of irrigation water was regular, resulting in the maintenance of a higher water depth. In the farmer field, weeds were removed only manually and the supply of water was irregular, resulting in a lower depth of water. Hence, the environmental conditions in the farmer field were more conducive for the emergence and prevalence of a higher number of weed species in the field proper, compared to the research field. Chandrasena[5] too had observed that the composition of weed flora in rice fields depended on the amount of standing water in the fields. The management of weed cover in the bunds also differed in the two fields. In the research field, weeds in bunds were slashed partially as well as intensively, on two occasions per cycle. In the farmer field, weeds in bunds were slashed only partially, mostly once during a cycle. However, the absence of a significant difference in the mean species richness of weeds on bunds of the two fields, in spite of the differences in slashing methods, indicates that slashing of weeds mainly reduces the cover of weeds, and not their species richness.

Rice field bunds serve as an important habitat for a variety of weeds, acting as a reservoir for their seeds as well. The differences in the distribution and abundance of weeds in the different bund surface types show that weed species vary in their ecological amplitudes. Weed species that occurred in all three bund surface types are those which have a wide ecological amplitude and can be considered as generalist species, inhabiting many different microhabitats. At the other extreme, species which were restricted to only one bund surface type are possibly specialists, with a narrow ecological amplitude. It was also evident that the distribution of some weed species (eg. *Leptochloa chinensis, Murdania spirata, Eclipta prostrata*) were different during the *Yala* and *Maha* cycles, where they were restricted during one cycle and were common during the subsequent cycle, and vice versa. However, whether these species differ in their distribution and abundance between the *Yala* and *Maha* cycles in a given rice field has to be confirmed by further studies.

As indicated by the higher β-diversity values, the higher differentiation of the composition of weeds within the shallow bund surface could be attributed to the diurnal and seasonal fluctuations of the floodwater level, causing temporal and spatial differences in soil moisture content, and hence affecting the germination of weeds. In addition, the temporal and spatial changes of the weed composition in the shallow bund surface may also be influenced by the higher shading effect by the growing rice canopy and the disturbance to the soil caused by the burrows and tunnels of rats and crabs. The lower similarity of the weed compositions in the deep and shallow bund surfaces could be attributed to the marked differences in surface area, soil moisture content and light regimes associated with the above bund surfaces.

In conclusion, the study shows that a rich composition of micro and macro flora are associated with the irrigated rice field ecosystem. The macrophytes were dominated by grasses and sedges. These floral communities exhibited a uniform pattern of seasonal colonisation and succession during a rice cultivation cycle, in relation to the growth of the rice crop and agronomic practices carried out. A difference in the species richness of weeds in relation to weed management and water management practices was clearly evident. The weed communities in the field bunds, while being rich in species, showed a differential distribution both spatially and temporally in different bund surfaces, in relation to soil moisture, surface area and light regimes associated with each bund surface. This study contributed towards the understanding of certain aspects related to the general ecology of the weed flora associated with the rice field ecosystem.

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Appendix 1: Floristic composition of rice field weeds, their life cycle, occurrence, habit and life-form.

[a] An=Annual; Pe=Perennial
[b] F=Field; B=Bund; D=Ditch (Water supply canal)
[c] A=Abundant; M=Moderate; O=Occasional; R=Rare
[d] Hydro= Hydrophytic; Hygro = Hygrophytic; Meso= Mesophytic
[e] Er=Erect; As= Ascending; Pr= Prostrate; Cr= Creeping; Rh= Rhizomatous, St=Stoloniferous; Tu=Tufted; Ti=Tillering; Cl= Climber; H=Herb; S=Shrub; Fl=Free-Floating; Em= Emergent; Sub = Submersed

Group/Family/ Species	Life cycle[a]	Major habitat[b] & (Occurrence)[c]	Habit[d]	Life-form[e]
Monocotyledons				
Poaceae				
Axonopus affinis Chase	An (Pe)	B (O),D (A)	Meso	Tu,St
A. compressus (Sw.) Beauv.	An (Pe)	B (O),D (A)	Meso	Tu,St
Chloris barbata	An	B (O)	Meso	Er-As
Cyanodon dactylon (L.)	Pe	F (O), B (M)	Meso	Pr-As, Rh
Dactyloctaenium aegyptium (L.) Richt.	An (Pe)	F (O), B (M)	Meso	Er-As
Digitaria ciliaris Schumach.	An	B (O)	Meso	Er-As
D. longiflora (Retz) Pers.	An	B (O)	Meso	Tu, Cr
Echinochloa colonum (L.) Link	An	F,B (A),D (O)	Hygro	Er,Tu
E. crus-galli (L.) Beauv	An	F,B (M)	Hygro	Er,Tu
E. stagnina (Retz.) Beauv.	An	F,B(O)	Hygro	Er,Tu
Eleusine indica (L.) Gaerth.	An	B (M)	Meso	Er-As,Tu,Ti
Eragrostis unioloides (Retz.) Nees ex Steud	An	B (M)	Meso	Er-As, Tu
Isachne globosa (Thunb.) Kuntze	An	F (A),B,D (M)	Hygro	Er,Cr,Tu,St
Ischaemum rugosum Salisb.	An	F (A),B (M)	Hygro	Er-As
I. timorense Kunth	An	F,B (O)	Hygro	Er-As
Leptochloa chinensis (L.) Nees	An (Pe)	F,B (O)	Meso	Er,Tu
Leersia hexandra Sw.	Pe	F,B,D (O)	Hygro	Er-As,Cr,Tu,Rh
Paspalum conjugatum Berg.	Pe	B (O)	Meso	Er,Tu,Cr,St
P. commersonii Lam.	Pe	F,B (O)	Hygro	Er,Tu,Cr,St
Panicum repens L.	Pe	B (A)	Meso	Er-As,Rh
Setaria geniculata (Lam.) Beauv.	An	B (R)	Meso	Er-As
Cyperaceae				
Cyperus rotundus L.	Pe	B (A)	Meso	Er,Rh,St
C. iria L.	An	F,B (M)	Hygro	Er,Tu
C. difformis L.	An	F; (M),B,D (O)	Hygro	Er,Ti
C. pilosus Vahl	Pe	F ,B (M)	Hygro	Er,Tu,Rh,St

Appendix 1 contd.

Group/Family/ Species	Life cycle[a]	Major habitat[b] & (Occurrence)[c]	Habit[d]	Life-form[e]
C. tenuispica Steud	An(Pe)	F (O)	Hygro	Er,Tu
C. haspan L.	Pe	F (A), B (M)	Hygro	Er, Tu, Rh
Fimbristylis miliaceae (L.) Vahl	An	F,B (A)	Hygro	Er,Tu,Ti
F. dichotoma (L.) Vahl	An	F,B (M)	Hygro	Er-As,Tu
F. schoenoides (Retz.) Vahl	An(Pe)	F (O), B (R)	Hygro	Er,Tu
Kyllinga brevifolia Rottboell	An(Pe)	B,D (O)	Meso	Er,Rh
K. nemoralis (J.R. & G.Forst) Dandy ex Hutchins.	Pe	B,D (O)	Meso	Er,Tu,Rh
Pycreus polystachyos (Rotboell) Beauv	An(Pe)	F,B (O)	Hygro	Er,Ti,Rh
P. pumilus (L.)	An	F,B (O)	Hygro	Er,Tu
Schoenoplectus juncoides (Roxb.) Palla	An	F,B (O)	Hygro	Er,Tu,Ti
Commelinaceae				
Commelina diffusa Burm.f.	An (Pe)	B,F(M);D(A)	Hygro	As,Pr,St
C. benghalensis L.	An (Pe)	B,D (M)	Hygro	As,Pr,St
Cyanotis axillaris (L.) Sweet	Pe	B,D (O)	Hygro	As,Pr,St
Murdania spirata (L.) Bruckner	Pe	B,D (M)	Hygro	As,Pr
Pontederiaceae				
Eichhornia crassipes (Mart.) Solms	An	F (R), D(O)	Hydro	Fl,St
Monochoria vaginalis (Burm.f.) Presl	An	F,B (M);D (O)	Hygro	Em,Ti
Eriocaulaceae				
Eriocaulon thwaitsii Koern.	An	F (M)	Hygro	Tu,Em
Dicotyledons				
Asteraceae				
Epaltes divaricata (L.)	An	B (O)	Meso	H,Er
Tridax procumbens L.	An	B (O)	Meso	H,Er-As
Ageratum conyzoides L.	An	B (A)	Meso	H, Er-As
Eclipta prostrata (L.) L	An	F (O), B (M)	Meso	H, Er-Pr
Eleutheranthera ruderalis (Swartz) Sch. Bip	An	B (M)	Meso	H,Er-As
Eupatorium odoratum L.	An	B (O)	Meso	S,Er
Emilia sonchifolia (L.) DC	An	B (O)	Meso	H,Er
Mikania cordata (Burm) Robinson	An	B (O)	Meso	Cl
Spilanthes iabadicensis A. H. Moore	An	B (M)	Meso	H, Er

Appendix 1 contd.

Group/Family/ Species	Life cycle[a]	Major habitat[b] & (Occurrence)[c]	Habit[d]	Life-form[e]
Sphaeranthus indicus L.	An	F(R), B (O)	Meso	S, Er
Vernonia cinerea (L.) Less	An	B (M)	Meso	H, Er
Scrophulariaceae				
Dopatorium junceum (Roxb.) Buch.-Ham.ex Benth.	An	F (M)	Hygro	H,Em, Sub
Lindernia rotundifolia (L.) Alston	An	F,B (M); D(R)	Hygro	H,Cr,Er
L. anagallis (Burm.f.) Pennell	An	B (M); D (O)	Hygro	H, As-Pr
L. pusilla (Willd.)Boldingh	An	F,B (0)	Hygro	H, Er-Pr
L. antipoda (L.) Alston	An	B(M);D (O)	Hygro	H,Er-Cr
L. crustacea (L.)F.Muell	Pe	F,B (M)	Hygro	H,Er-Pr
L. hyssopioides (L) Haines	An	F,B (O)	Hygro	H,Er-Pr
Malvaceae				
Abutilon asiaticum L.	Pe	B (R)	Meso	S,Er
Sida rhombifolia L.	Pe	B (O)	Meso	S,Er
Urena lobata L.	Pe	B (O)	Meso	S,Er
Onagraceae				
Ludwigia decurrens Walt.	An	F (O);B (M)	Hygro	H, Er
L. perennis L.	An	F (O);B (M)	Hygro	H, Er
L. hyssopifolia (G.Don) Exell	An	F (O);B (M)	Hygro	H, Er
Fabaceae				
Desmodium triflorum (L.) DCH,	Pe	B (A);D (M)	Meso	Pr
Alyssicarpus vaginalis DC.	An	B (M)	Meso	Pr
Cassia tora L.	An(Pe)	B (O)	Meso	H, Er
Euphorbeaceae				
Euphorbia hirta L.	An	B (O)	Meso	H, Er-As-Pr
E.hypericifolia L.	An	B (O)	Meso	H,As
E. rubicunda L.	An	B (O)	Meso	H, Er
E. indica Lam.	An	B (R)	Meso	H, Er
Phyllanthus debilis Klein ex Willd.	Er H,	B(M)	Meso	H, Er
Convolvulaceae				
Ipomoea aquatica Forsk.	An	F,B,D (O)	Hygro	Cr
I. triloba L.	An	B (O)	Meso	Cl
I. pes-tigridis L.	An	B (R)	Meso	Cl

Appendix 1 contd.

Group/Family/ Species	Life cycle[a]	Major habitat[b] & (Occurrence)[c]	Habit[d]	Life-form[e]
<u>Rubiaceae</u>				
Borreria laevis (Lamk.)Griseb.	Pe	B (M)	Meso	Er, H
Hedyotis corymbosa (L.) Lamk.	An	B (M)	Meso	Er, H
Spermococe assungera L.	An	B (O)	Meso	Er, H
<u>Lamiaceae</u>				
Basilicum polystachyon L.	An	B (M)	Meso	Er, H
Leucas zeylanica (L.)R.Br.	An	B (O)	Meso	Er, H
<u>Amaranthaceae</u>				
Alternanthera sessilis (L.) DC	Pe	F,B,D (O)	Hygro	Cr
<u>Mimosaceae</u>				
Mimosa pudica L.	Pe	B (O)	Meso	H, As-Pr
<u>Sphenocleaceae</u>				
Sphenoclea zeylanica Gaerth.	An	F (M), B (R)	Hygro	H, Er
<u>Elatinaceae</u>				
Elatine triandra Schkuhr.	An	F (A)	Hydro	Cr, Sub
<u>Apiaceae</u>				
Centella asiatica (L.) Urb.	Pe	B,D (O)	Hygro	Cr
<u>Pterydophytes</u>				
Salviniaceae				
Salvinia molesta D.S.Mitchell	An (Pe)	F (A)	Hydro	Fl, St
<u>Marsiliaceae</u>				
Marsilia quadrifolia L.	Pe	F,B (A); D (O)	Hygro	Hygro

Appendix 2: Microflora and macrofungi, their life-forms and occurrence in the rice field ecosystem.

[a] Ff = Free Floating; Co = Colonial; At = Attached; F = Free; Fi = Filamentous; S = Solitary; Ag = Aggregate; M = Motile; [b] C = Common, UC = Uncommon

Phylum/Group/Genus	Life-form[a]	Occurrence[b]
Cyanophyta (BGA)		
Aphanothece Naegeli	Co, Ff	C
Aphanocapsa Naegeli	Co, Ff	UC
Anabaena Bory	Fi, Ff/At	C
Coelosphaerium Naegeli	Co, Ff	C
Merismopedia Meyen	Co, Ff	UC
Microcyctis Kutzing	Co, Ff	UC
Nostoc Vaucher	Co, At/F	UC
Oscillatoria Vaucher	Fi	C
Chlorophyta		
Filamentous algae		
Spirogyra Link	Fi, Ff	C
Flagellated forms		
Volvox Linnaeus	S, Co, M	UC
Gonium Mueller	S, Co, M	UC
Chlamydomonas Ehrenberg	S, Co, M	C
Desmids		
Ankistrodesmus Corda	S/Ag, Ff	C
Cosmarium Corda	S, Ff	C
Closterium Nitzsch	S, Ff	UC
Docidium deBrebisson	S, Ff	UC
Euastrum Ehrenberg	S, Ff	C
Enteromorpha Link	Co, Ff/ At	UC
Microspora Thuret	Fi, Ff	UC
Micrasterias Agardh	S, Ff	C
Netrium Naegeli	S, Ff	UC
Pleurotaenium Naegeli	S, Ff	C
Penium deBrebisson	S/ Ff	UC
Protosiphon Klebs	Co, At	UC

Appendix 2 contd.

Phylum/Group/Genus	Life-form[a]	Occurrence[b]
Pediastrum Meyen	Co, Ff	C
Scenedesmus Meyen	Co, Ff	UC
Tetraedron Kuetzing	S, Ff	UC
Euglenophyta		
Euglena Ehrenberg	S, M	C
Phacus Dujardin	S, M	C
Bacillariophyta (Diatoms)		
Frustulia	-	UC
Navicula	-	C
Macrofungi		
Agaricales		
Agaricus spp.	-	C
Coprinus spp.	-	C
Lycoperdales		
Lycoperdon	-	UC

Appendix 3: Composition and relative abundance of weed flora in the three bund surface types during the *Maha* 1996 and *Yala* 1997 cycles, at 90 days after transplanting.

Scores: 1=Rare; 2=Occasional; 3=Moderate; 4=Common; 5=Abundant

Cycle	*Maha* 1996									*Yala* 1997								
Bund Surface Type	Flat			Shallow			Deep			Flat			Shallow			Deep		
Site (Replicates)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Fimbristylis miliacea	1	2	1	5	5	5	3	3	2	1	1	1	5	5	5	2	2	2
Marsilia quadrifolia	1	1	-	1	3	2	1	2	1	1	1	-	2	3	1	2	1	1
Commelina diffusa	5	2	-	4	1	-	3	2	-	4	1	-	3	1	-	2	-2	
Echinochloa colonum	1	1	1	-	-	1	1	1	1	2	1	1	2	1	1	-	1	1
Eragrostis unioloides	3	1	3	-	1	2	2	1	2	1	-	1	-	2	1	-	-	1
Panicum repens	3	3	-	2	-	-	1	-	-	3	1	-	-	1	-	1	2	-
Digitaria nuda	-	1	2	-	1	-	2	1	1	-	-	1	-	1	-	1	-	1
Cyanodon dactylon	3	-	-	1	-	-	1	-	-	-	3	-	-	1	-	2	1	-
Leptochloa chinensis	-	-	-	-	-	-	1	-	-	-	2	1	-	1	1	-	1	-
Cyperus iria	1	2	-	-	1	-	1	-	-	-	-	1	1	-	1	-	1	-
Murdania spirata	-	-	2	-	-	2	-	2	2	-	-	-	-	-	-	-	2	2
Hedyotis corymbosa	-	1	-	-	1	1	2	2	2	1	-	-	-	1	-	2	1	2
Phyllanthus debilis	1	1	1	-	-	1	2	1	2	1	-	-	1	-	-	2	-	1
Eclipta prostrata	-	2	-	-	1	-	2	2	-	-	-	-	-	-	-	1	1	-
Alternanthera sessilis	-	-	1	-	-	1	-	1	-	-	-	-	-	1	-	-	-	1
Isachne globosa	2	-	2	3	-	-	-	-	-	1	-	2	2	-	2	-	-	-
Cyperus haspan	-	-	-	-	1	-	-	-	-	-	2	-	-	1	-	-	-	-
Cyperus rotundus	2	1	-	-	2	-	-	-	-	3	3	-	-	1	-	-	-	-
Eleusine indica	2	2	3	-	-	-	2	2	1	3	2	2	-	-	-	2	-	-
Dactyloctenium aegyptium	2	2	2	-	-	-	1	1	1	2	-	1	-	-	-	1	1	-

Appendix 3 contd.

Cycle	Maha 1996									Yala 1997								
Bund Surface Type	Flat			Shallow			Deep			Flat			Shallow			Deep		
Site (Replicates)	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Paspalum conjugatum	-	-	-	-	-	-	2	-	1	1	1	-	-	-	-	1	-	-
Euphorbia hirta	1	-	-	-	-	-	1	-	-	1	-	-	-	-	-	1	-	-
Cyperus pumilus	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-
Ludwigia perennis	-	-	-	1	1	1	-	2	-	-	-	-	-	1	1	-	1	-
Ludwigia hyssopifolia	-	-	-	-	-	-	2	-	-	-	-	-	-	1	-	1	-	-
Lindernia rotundifolia	-	-	-	-	1	-	-	1	1	-	-	-	1	1	1	1	1	2
Echinochloa crus-galli	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-
Cyperus pilosus	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Kyllinga nemoralis	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Monochoria vaginalis	-	-	-	-	-	2	-	-	-	-	-	-	-	1	2	-	-	-
Ischaemum timorense	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	
Ischaemum rugosum	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	1	1
Leersia hexandra	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Fimbristylis schoenoides	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Ageratum conyzoides	-	-	-	-	-	-	2	3	2	-	-	-	-	-	-	1	3	2
Vernonia cineria	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	2
Spilanthes iabadicensis	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-		-	2
Borreria laevis	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	2	-	-
Desmodium spp.	-	-	-	-	-	-	2	-	2	-	-	-	-	-	-	2	-	3
Euphorbia hypericifolia	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	-
Lindernia antipoda	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	1	1	1
No.of spp. in each surface	19			23			34			19			21			31		
Total spp. in each cycle	40									36								

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