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*RESEARCH, REVIEWS, PRACTICES,  
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Weed Community Dynamics  
in the System of Rice Intensification (SRI)  
and the Efficacy of Mechanical Cultivation  
and Competitive Rice Cultivars  
for Weed Control  
in Indonesia

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**ABSTRACT.** The system of rice intensification (SRI) prescribes the use of young seedlings, planted at reduced densities and managed using reduced irrigation and frequent mechanical weeding, as a means of optimizing rice yields and reducing input costs. Such changes in management practice have been known to result in prominent shifts in weed flora, which if anticipated could help refine future weed control strategies. This study, conducted at four locations in West Java, Indonesia, examines the effects of two complimentary control tactics, mechanical cultivation and competitive rice cultivars, on individual weed species, broader weed classes and entire weed communities. Relative dry weights of individual weed species ranged widely from site-to-site. Differences in dry weight among weed classes were observed, with sedges accumulating greater biomass than either broadleaved weeds or grasses in nonweeded plots across all sites and cultivars. Mechanical cultivation was effective in reducing the dry weight, density, and species number of all weed classes. Effective weed control by mechanical cultivation also resulted in weed communities with lower species richness, greater dominance by fewer species, and hence lower overall diversity. The weed competitive cultivar (Sarinah) more effectively suppressed the dry weight of sedges and grasses than did the control variety (IR64), but had no influence on the dry weight of broadleaved weeds. Despite reducing total weed dry weight by 32%, use of a competitive cultivar had no effect on the density and species number of weed classes or any of the community-scale measures of diversity. Although competitive cultivars may have little effect on the relative abundance of resident weed species from an ecological standpoint, this should not diminish the practical potential such cultivars may have in reducing the number and intensity of weeding operations. doi:10.1300/J064v30n04\_03 [Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <<http://www.HaworthPress.com>> © 2007 by The Haworth Press, Inc. All rights reserved.]

**KEYWORDS.** Rice, weed diversity, weed suppression, competitive cultivars, SRI, mechanical weed control

## INTRODUCTION

Of the many pests of rice (*Oryza sativa* L.), weeds pose the single most consistent early season threat to grain yields, and as such are controlled by a variety of methods which include flooding, tillage, herbicide application, mechanical cultivation, and hand weeding (Johnson et al., 2003). Not only do moisture regime (e.g., irrigated, rainfed lowland, upland) and

method of crop establishment (e.g., transplanted, direct seeded) affect the severity of weed infestations, but they can also cause fundamental changes in the resident weed communities (Sarker et al., 2002). These differences in community structure include changes in relative dominance among individual weed species, and can ultimately contribute to changes in species richness and other more comprehensive measures of diversity (Tomita et al., 2003). Knowledge concerning which weed species will likely be the most common or troublesome in a given cropping system is important in that such information can then be used to develop effective management strategies appropriate to that system.

The system of rice intensification (SRI) is a novel approach to rice production that manipulates some of the most prominent features of conventional lowland rice, namely soil moisture, seedling age, and planting density in a dual attempt to optimize growing conditions for individual plants and more importantly maximize production from entire crop stands. Aspects of SRI which differ from conventional practices are its use of younger seedlings (8 to 12-days-old) transplanted at reduced seedling densities (1 plant per hill at a 25 cm  $\times$  25 cm spacing or wider) into fields that are managed under an intermittent irrigation regime that allows for aerobic soil conditions. A description of SRI practices has been published by Stoop et al. (2002) and further contrasted with conventional management practices by Sheehy et al. (2005). Cultural changes such as these may help improve grain production; however, these very same practices have also tended to make SRI more weed-prone and thus require more laborious weeding operations (Rakotomalala, 1997; McHugh, 2002; Moser and Barrett, 2003; Latif, 2005). A range of weed control strategies, which include hand weeding, mechanical cultivation, herbicide application (2, 4-D), mulching, and a combination of both hand weeding and herbicide have been used in SRI fields with varying economic costs and degrees of success (Randriamiharisoa, 2002; Latif et al., 2005). Using an approach adapted from other weed-prone rice production systems, weed competitive rice varieties are also being considered as a means for reducing the labor and chemical inputs required to effectively and economically manage weeds in SRI (Stoop et al., 2002; Haden, 2006).

At present, no research has yet described the weed flora commonly found in SRI fields. Furthermore, the direct effects of SRI-prescribed management strategies on these weed communities have not been rigorously examined. In other production systems similar to SRI where flooding of rice fields is either delayed (e.g., direct seeded systems) or eliminated altogether (e.g., aerobic rice, upland systems), such management changes have resulted in increased weed emergence, greater

percent coverage by weeds relative to rice, and increased species diversity (Morita et al., 2002; Tomita et al., 2003). In a prescriptive study conducted in Bangladesh, Sarker et al. (2002) observed that by increasing the intensity of weeding regime, the density and dry weight of weeds can be reduced in direct seeded rice. Although few studies have been conducted detailing the specific effects of mechanical cultivation on weed community composition, individual weed species can respond differently to tillage and chemical weed control (De Datta et al., 1981). While the use of weed suppressive cultivars have yet to become a widely adopted management tactic in rice, they have already shown the ability to reduce weed dry weights of both naturally occurring multi-species weed infestations as well as experimentally generated mono-specific stands of *Echinochloa colona* (Gibson et al., 2003; Fischer et al., 1997). Information regarding management-induced shifts in weed flora could help predict which weed pests might cause future problems and perhaps suggest which strategies are likely to be more effective and sustainable (Bhagat et al., 1999).

For the purpose of providing information upon which management decisions can be based, the primary intent of this field study is to evaluate the effects of mechanical cultivation and weed competitive cultivars on the abundance, dry weight, and diversity of weed species occurring in SRI fields. In this study, we aim to answer the following two questions: (1) What are the dominant naturally occurring weeds in SRI managed rice fields in Indonesia? (2) How do these weed species and the larger weed classes to which they belong respond to mechanical cultivation and the use of competitive cultivars?

## **MATERIALS AND METHODS**

### ***Site Characterization and Experimental Design***

Experiments were conducted on four sites during the 2004-2005 wet season in the West Java province of Indonesia. Each of the four trials (Kareng Resik, Cikoneng, Rata Wangi, and Ciherang) were conducted on farmers' fields, and involved partner farmers with no fewer than two seasons experience using the system of rice intensification (SRI). Site history, geographic parameters, and soil properties are reported in Table 1. Soil properties were analyzed from composite soil samples consisting of 15 random samples per location, collected to a depth of 20 cm.

TABLE 1. Description of soil properties, site characteristics, and cropping history for four sites in West Java, Indonesia.

| Parameter                             | Kerang Resik  | Cikoneng   | Rata Wangi                                       | Ciherang  |
|---------------------------------------|---|--|--|---|
| Soil Group <sup>a</sup>               | Nitisols  | Nitisols   | Nitisols   | Nitisols  |
| Soil texture class                    | Silty clay loam   | Clay loam  | Clay   | Silty clay  |
| Sand (%)                              | 19.8  | 21.0   | 4.65   | 12.1  |
| Silt (%)                              | 41.0  | 42.5   | 30.0   | 46.5  |
| Clay (%)                              | 39.2  | 36.5   | 65.3   | 41.4  |
| pH                                    | 6.06  | 6.25   | 6.4  | 6.19  |
| P (mg kg <sup>-1</sup> ) <sup>b</sup> | 10.18   | 2.43   | 1.06   | 3.41  |
| K (mg kg <sup>-1</sup> ) <sup>b</sup> | 138.38  | 170.43   | 95.81  | 201.25  |
| Total N (%) <sup>c</sup>              | 0.28  | 0.29   | 0.18   | 0.14  |
| Total C (%) <sup>c</sup>              | 2.83  | 2.85   | 1.93   | 1.58  |
| Altitude (m)                          | 352.00  | 392.00   | 52.00  | 44.00   |
| Lat/Long                              | 108°14'26" E,<br>07°18'48" S                              | 108°13'24" E,<br>07°17'27" S   | 108°38'01" E,<br>07°30'47" S                     | 108°37'48" E,<br>07°29'36" S  |
| Site history                          | Conventional irrigated rice, two to three crops per year. | 4 month dry fallow preceded by 6 month vegetable crop. When in rice, two crops per year. | Conventional irrigated rice, two crops per year. | Two crops per year rice cultivation via SRI methods for past 4 years. |

<sup>a</sup>Source: (Adapted from FAO, 1988).

<sup>b</sup>Morgan soil test values.

<sup>c</sup>Analyzed by dry combustion.

Regional rainfall patterns are unimodal, consisting of a wet season beginning in late October and lasting through June followed by a hot dry season between July and early October.

The experiment followed a split-plot design replicated three times at each of the four sites, with weeding regime and rice cultivar as the main plot (3 m × 6 m) and subplot (3 m × 3 m) factors, respectively. Two weeding treatments were included: natural weed growth (W1) and intensive mechanical cultivation (W2). In the W1 treatment, no weed control measures were used and all weeds were left undisturbed. The mechanically cultivated treatment (W2) utilized a rotary weeder for between-row weeding at 8 and 16 days after transplanting (DAT), followed by two weeding operations with a traditional wooden weeding instrument at 24 and 32 DAT. Lateral vegetative growth by the rice plants precipitated the move to the traditional tool so that damage to the crop by the machine

could be avoided. This experiment was part of a larger yield trial evaluating the performance of a diverse collection of rice cultivars for weed competitive ability. We selected two cultivars for this experiment, IR64 and Sarinah, using the following criteria. IR64 is a short-statured, semi-dwarf, *indica* variety, typical of those released by IRRI in the mid-1980s. Since IR64 accounts for the majority of rice planted in Indonesia, it was included as a standard. Sarinah is a local Indonesian variety of the *tropical japonica* subspecies (formerly *javanica*) that has been observed to be a notably good competitor with weeds according to preliminary yield trials (Haden, Chapter 2). The duration of both cultivars was 115 days.

### ***SRI Methods***

At each site, fields were cultivated, leveled, and harrowed prior to the application of compost at a rate of 7 t ha<sup>-1</sup>. Compost consisted of 60% cow and goat manure, 35% leguminous vegetation, and 5% ash. The mixture was covered, fermented for 2 weeks, and applied to the soil 3-5 days prior to planting. Fields were harrowed and leveled a second time to incorporate compost and remove any remaining weeds 1 day before transplanting. Inorganic fertilizers were not used in this study. Pre-germinated seeds were sown in plastic trays (25 cm × 25 cm × 4 cm) containing a 1:1 mixture of sieved (2 mm) compost and bulk soil. Seedlings were watered daily until transplanting at 10 days. Following the SRI methods described by Sheehy et al. (2004) and Barison (2002), single seedlings (10-days-old) were transplanted in a 30 × 30 cm square spacing pattern to facilitate weeding operations. Given that there was only one plant per hill, instances of seedling mortality occasionally required replacing seedlings at 8 and 16 DAT to fill gaps in the crop stand. An alternating wet-dry irrigation regime described by McHugh (2002) was followed, where every 7-8 days throughout the vegetative stage plots were flooded to 2 cm and then drained between irrigation events. Soil conditions in the intervals were moist but not saturated. At panicle initiation (65-70 days) fields were flooded to 2 cm and maintained until 2 weeks prior to harvest, at which point they were drained.

### ***Sampling Procedures and Diversity Indices***

Nondestructive weed counts were conducted at 16 and 32 DAT using a randomly placed 0.25 m<sup>2</sup> quadrat and the number of plants belonging to individual weed species was recorded for each subplot in both treatments (W1 and W2). Total weed density of the weed communities

was compiled by summing the species totals in each subplot. Species richness (S) was the number of species with at least one individual present in the sample area (Hurlbert, 1971). Dominance of the sampled communities was assessed using Simpson's index (C) (Simpson, 1949). Diversity of the weed communities was determined using the reciprocal form of the Simpson's index (D) and the McIntosh index of diversity (U) (McIntosh, 1967). Species evenness for each community was obtained using the McIntosh evenness index (E) (McIntosh, 1967). The above set of diversity measures were computed using the following equations in which  $X_i$  represents the number of individuals in the  $i$ -th species of a sample, and  $X_o$  equals the total number of individuals in the sample.

$$\text{Species richness (S) = number of species per unit area sampled} \quad (1)$$

$$\text{Simpsons index (C) = } \sum (X_i/X_o)^2 \quad (2)$$

$$\text{Diversity (D) = } 1/C \quad (3)$$

$$\text{McIntosh (U) = } 1 - \sqrt{\sum (X_i/X_o)^2} \quad (4)$$

$$\text{McIntosh (E) = } (X_o - U)/(X_o - X_o/\sqrt{S}) \quad (5)$$

At 60 DAT, weeds were destructively harvested from a 0.25 m<sup>2</sup> quadrat, taken near the center of each subplot to avoid edge effects. All weed shoots were washed to remove soil, removed of their roots, and sorted by species. After being air-dried to a constant weight on roof-top drying racks, weeds were weighed to assess dry weight for each species. Species dry weights were summed to represent total weed dry weight (DW) per 0.25 m<sup>2</sup>. As with earlier samplings species richness (S) was the number of weed species present in each sample, though at 60 DAT presence was determined by a dry weight greater than zero rather than density. Relative dry weight (RDW) was calculated as a biomass derived measure of community dominance using the following formula:

$$\text{Relative dry weight (RDW) = } \left\{ \frac{\text{(Dry weight of a given species)}}{\text{(total dry weight)}} \right\} \times 100 \quad (6)$$

### ***Statistical Analysis***

SAS (SAS Institute, 2001) was used to perform a series of analysis of variance (ANOVA) tests. For each individual site, a mixed model (PROC MIXED) was used to evaluate the effect of weeding regime (W1 and W2) and cultivar (IR64 and Sarinah) on both total weed density and

the density of each weed class. Blocks were considered a random variable and both weeding regime and cultivar served as fixed effects. A mixed model was also used to assess the effect of weeding treatment and cultivar on dry weight and species number of weed classes, total weed dry weight, and all measures of community composition including species richness, dominance, diversity, and evenness across all sites. Since these tests encompassed a generalized response observed across all sites, both site and block were classified as random effects while treatment and cultivar were again considered fixed. For almost all tests in this study treatment and cultivar means were estimated concurrently and compared using the differences of least squared means. The only test that varied marginally from this procedure was that which used a mean of both cultivars to compare the changes in species number of individual weed classes in response to the two weeding treatments. For all tests, a significance level of 5% ( $P < 0.05$ ) was used to determine differences among mean values.

## RESULTS AND DISCUSSION

### *Relative Dry Weight of Weed Species at Experimental Sites*

The community composition of nonweeded plots (W1) at peak weed growth (60 DAT) and the relative importance of individual species (as measured by their relative dry weight) varied dramatically between sites (Table 2). Karang Resik was dominated by a mix of *Fimbristylis miliacea* and weedy rice (unknown *Oryza* sp.), with *Cyperus difformis* and *Cyperus iria* also present but having lower dry weights. At Cikoneng, *C. iria* made up more than half of the weed dry weight present. Other prominent species at Cikoneng included *C. difformis* and the perennial grass *Leptochloa chinensis*. The annual grass *Echinochloa crus-galli* was co-dominant with *F. miliacea* at Rata Wangi, with *C. difformis* and the relatively rare *Scirpus juncooides* also contributing a substantial amount of biomass. The Ciherang site was notable in that it was dominated by *Monochoria vaginalis*, a common broadleaved species that typically produces less biomass than either sedge or grass weeds in these cropping systems. *C. difformis* and *E. crus-galli* were also important species at this site. Owing to variability in community composition, we grouped these species into broader weed classes for subsequent analysis. This approach was justified given that members of a related weed class are likely to play similar functional roles in the weed community and more importantly would

TABLE 2. Relative dry weight and total dry weight of weed species from nonweeded plots at each of four sites in West Java, Indonesia, 60 days after transplanting.

| Species  | Family        | Common Name                 | Life Cycle | Weed Class | Relative Dry Weight (%) |       |       |       |
|--|---------------|-----------------------------|------------|------------|-------------------------|-------|-------|-------|
|  |               |                             |            |            | KR                      | CK    | RW    | CH    |
| <i>Alternanthera sessilis</i> (L.) R. Br. ex DC.     | Amaranthaceae | Sessile joyweed             | p          | B          | 0.20                    | 0.75  | 0.00  | 0.05  |
| <i>Cyperus difformis</i> L.                          | Cyperaceae    | Smallflower umbrella sedge  | a          | S          | 16.44                   | 9.27  | 26.32 | 29.83 |
| <i>Cyperus iria</i> L.                               | Cyperaceae    | Rice flat sedge             | a          | S          | 9.62                    | 54.20 | 2.17  | 0.88  |
| <i>Digitaria ciliaris</i> (Retz.) Koel.              | Poaceae       | Crabgrass                   | a          | G          | 0.51                    | 0.43  | 0.00  | 0.00  |
| <i>Echinochloa crus-galli</i> (L.) P. Beauv.         | Poaceae       | Barnyard grass              | a          | G          | 3.57                    | 3.25  | 33.43 | 24.45 |
| <i>Eleocharis atropurpurea</i> (Retz.) J. & K. Presl | Cyperaceae    | Purple spikerush            | a          | S          | 0.00                    | 0.00  | 0.28  | 0.00  |
| <i>Fimbristylis miliacea</i> (L.) Vahl               | Cyperaceae    | Globe fringerush            | p          | S          | 35.48                   | 21.13 | 41.57 | 3.07  |
| <i>Leptochloa chinensis</i> (L.) Nees                | Poaceae       | Chinese sprangletop         | p          | G          | 1.66                    | 15.38 | 0.00  | 0.50  |
| <i>Ludwigia adscendens</i> (L.) Hara                 | Onagraceae    | Creeping water primrose     | p          | B          | 0.43                    | 1.19  | 0.48  | 2.23  |
| <i>Ludwigia octovalvis</i> (Jacq.) Raven             | Onagraceae    | Longfruited primrose-willow | p          | B          | 1.28                    | 6.20  | 0.00  | 4.92  |

TABLE 2 (continued)

| Species  | Family           | Common Name  | Life Cycle | Weed Class | Relative Dry Weight (%) |        |        |        |
|--|------------------|--------------|------------|------------|-------------------------|--------|--------|--------|
|  |                  |              |            |            | KR                      | CK     | RW     | CH     |
| <i>Marsilea minuta</i> L.                                | Marsiliaceae     | Water clover | p          | B          | 0.00                    | 0.35   | 3.17   | 0.00   |
| <i>Monochoria vaginalis</i> (Burm. F.) C. Presl ex Kunth | Pontederiaceae   | Monochoria   | p          | B          | 3.28                    | 3.11   | 12.42  | 39.47  |
| <i>Scirpus juncooides</i> Roxb.                          | Cyperaceae       | Bulrush      | a          | S          | 0.00                    | 0.00   | 16.67  | 0.18   |
| <i>Bacopa</i> spp.                                       | Scrophulariaceae | Water hyssop | p          | B          | 0.37                    | 0.00   | 0.00   | 1.58   |
| <i>Oryza</i> spp.  | Poaceae          | Weedy rice   | a          | G          | 29.81                   | 0.00   | 1.00   | 0.00   |
| Total weed dry weight (g/0.25 m <sup>2</sup> )           |                  |              |            |            | 105.90                  | 127.10 | 139.80 | 106.80 |

Life cycle: annual (a), perennial (p).

Weed class: broadleaved weed (B), grass (G), sedge (S).

Sites: Kerang Resik (KR), Cikong (CK), Rata Wangi (RW), Ciherang (CH).

be expected to behave in a similar way in response to our experimental treatments (Bhagat et al., 1999).

### **Weed Class Dry Weights**

Intensive weeding drastically reduced weed dry weights of all weed classes harvested at 60 DAT across the four experimental sites (Table 3). Mean dry weight of sedges was significantly higher than both grass and broadleaved weeds in nonweeded (W1) plots, but weeding four times prior to canopy closure reduced the dry weight of all weed classes to equally low levels. Bhagat et al. (1999) found that at 60 days after direct seeding rice, sedges consistently produced more biomass than either grass or broadleaved weeds when no additional weed control measures were employed. When under severe competition, as seen in the nonweeded treatment, the cultivar Sarinah was more effective in suppressing the weed growth of grasses and sedges than was IR64, as reflected by its significantly lower dry weights for these two weed classes. No difference in the dry weight of broadleaved weeds in the nonweeded treatment was found between the two cultivars (Table 3). The effective use of competitive cultivars to suppress grasses, broadleaved weeds, and mixed infestations that include sedges has been reported (Garrity et al., 1992; Gibson et al., 2003). There was no cultivar effect observed in the weeded treatment (W2) as there was no significant difference in weed dry weight among any of the weed classes for both cultivars. This is not a surprising result since it reflects the greater efficacy of the

TABLE 3. Effect of weeding regime and rice cultivar on dry weight of different weed classes harvested at 60 days after transplanting, across four experimental sites.

| Weeding Regime | Cultivar | Weed Dry Weight (g/0.25 m <sup>2</sup> ) |            |            |
|----------------|----------|--|------------|------------|
|                |          | Broadleaved                              | Grasses    | Sedges     |
| W1             | IR64     | 22.75a (a)                               | 35.09a (a) | 79.92a (b) |
|                | Sarinah  | 16.42a (a)                               | 21.90b (a) | 53.63b (b) |
| W2             | IR64     | 1.10b (a)                                | 0.10c (a)  | 0.29c (a)  |
|                | Sarinah  | 0.68b (a)                                | 0.11c (a)  | 0.34c (a)  |

W1 = Natural weed growth; W2 = Mechanically weeded four times.

Note: Means within columns (each weed class) followed by a different letter not enclosed by parenthesis are significantly different at  $P < 0.05$ ; Means across each row followed by a different letter enclosed by parenthesis are significantly different at  $P < 0.05$ .

mechanical weeding regime in controlling weed growth as compared to the suppressive ability of any particular rice cultivar on its own. Our results support the view that weed suppressive cultivars may be an economical strategy for reducing the number of weeding operations or herbicide applications, but not eliminating their use altogether (Dingkuhn et al., 1999; Gealy et al., 2003; Gibson et al., 2003).

### *Weed Density Among Classes*

There was considerable site-to-site variability in both the total weed density and the densities of different weed classes in nonweeded plots (Table 4). Sedges were the most abundant class in the Kerang Resik and Rata Wangi sites, whereas broadleaved weeds were the most common in the Cikoneng and Ciherang sites. At all sites and sampling times, grasses were the least abundant weed class in nonweeded plots. The Cikoneng site had a notably high total weed density primarily because of an increased abundance of broadleaved weeds and to a lesser extent sedges. This is perhaps a result of this site having been used for mixed vegetable production during the previous wet season (6 months), and then left fallow for an additional 4 months prior to the start of this experiment. A site with this cropping history is likely to have had increased rates of weed seed recruitment into its soil seed bank (Akobundu et al., 1999).

Immediately prior to the second weeding (16 DAT) the effects of weeding regime and rice cultivar on the density of weed classes and total weed density were inconsistent (Table 4). The Rata Wangi site showed no significant impact of weeding regime or cultivar on the density of particular weed classes or total weed density. In the Cikoneng and Ciherang sites, mechanical weeding significantly reduced total weed density of plots containing the cultivar IR64, while the plots containing Sarinah reflected already low-weed densities (perhaps due to improved suppressive ability) and thus significant additional reductions upon weeding were not observed. At the Kerang Resik site, nominal reductions in total weed density in response to mechanical weeding were observed for both cultivars at 16 DAT however the effect was only significant in plots containing Sarinah. A likely explanation for the inconsistent effects of the rice cultivars is that in some locations the rice plants may have still been too small at 16 DAT to inhibit weed seed germination or weed growth. The fact that only the first of four mechanical

TABLE 4. Effect of weeding treatment and rice cultivar on density (per 0.25 m<sup>2</sup>) of major weed classes and total weed density at four sites in Indonesia, sampled 16 and 32 days after transplanting.

| DAT        | Cultivar | Treatment | Kerang Pesiik |         |         |         | Cikoneng    |         |         |         |
|------------|----------|-----------|---------------|---------|---------|---------|-------------|---------|---------|---------|
|            |          |           | Broadleaved   | Grasses | Sedges  | Total   | Broadleaved | Grasses | Sedges  | Total   |
| 16         | IR64     | W1        | 20.33ab       | 14.33a  | 28.33a  | 63.33ab | 250.67a     | 21.00a  | 126.67a | 398.33a |
|            | IR64     | W2        | 13.66b        | 3.66b   | 21.00a  | 38.33b  | 89.66b      | 11.66a  | 52.00a  | 155.00b |
|            | Sarinah  | W1        | 29.33a        | 8.00ab  | 40.33a  | 78.33a  | 108.00b     | 12.00a  | 84.33a  | 205.33b |
|            | Sarinah  | W2        | 12.33b        | 4.33b   | 20.00a  | 37.67b  | 50.66b      | 15.00a  | 57.66a  | 124.00b |
| 32         | IR64     | W1        | 19.66a        | 11.66a  | 28.00a  | 60.33a  | 127.67a     | 14.00ab | 135.33a | 279.33a |
|            | IR64     | W2        | 4.66b         | 0.33b   | 10.00a  | 16.00b  | 82.33b      | 11.33b  | 40.33c  | 135.00b |
|            | Sarinah  | W1        | 17.66a        | 7.33a   | 23.00a  | 49.00a  | 103.33ab    | 18.33a  | 95.33b  | 221.00a |
|            | Sarinah  | W2        | 7.00b         | 1.66b   | 6.66a   | 17.00b  | 74.33b      | 12.00ab | 25.33c  | 114.00b |
| Rata Wangi |          |           |               |         |         |         |             |         |         |         |
| 16         | IR64     | W1        | 3.33a         | 5.00a   | 32.00a  | 40.66a  | 33.33a      | 5.66a   | 58.33a  | 106.33a |
|            | IR64     | W2        | 2.00a         | 2.66a   | 11.00a  | 16.00a  | 8.00c       | 0.66b   | 1.00b   | 9.66b   |
|            | Sarinah  | W1        | 2.33a         | 3.66a   | 13.00a  | 20.00a  | 24.66ab     | 2.66ab  | 7.33b   | 36.00b  |
|            | Sarinah  | W2        | 5.33a         | 3.00a   | 17.33a  | 26.33a  | 10.33bc     | 0.00b   | 4.33b   | 14.66b  |
| 32         | IR64     | W1        | 13.00a        | 3.00a   | 41.33a  | 57.33a  | 39.33a      | 4.66a   | 26.00a  | 76.33a  |
|            | IR64     | W2        | 1.33a         | 1.33a   | 8.00b   | 10.66b  | 4.00b       | 0.66b   | 1.66c   | 6.33b   |
|            | Sarinah  | W1        | 7.33a         | 4.00a   | 36.00ab | 47.33ab | 57.33a      | 5.00a   | 13.00b  | 77.00a  |
|            | Sarinah  | W2        | 5.33a         | 1.00a   | 8.33b   | 14.66b  | 2.667b      | 1.00b   | 1.33c   | 5.00b   |
| Ciherang   |          |           |               |         |         |         |             |         |         |         |

DAT = Days after transplanting; W1 = Natural weed growth; W2 = Mechanically weeded.

Note: Means followed by common letter (within same sampling date and column) are not significantly different at  $P < 0.05$ .

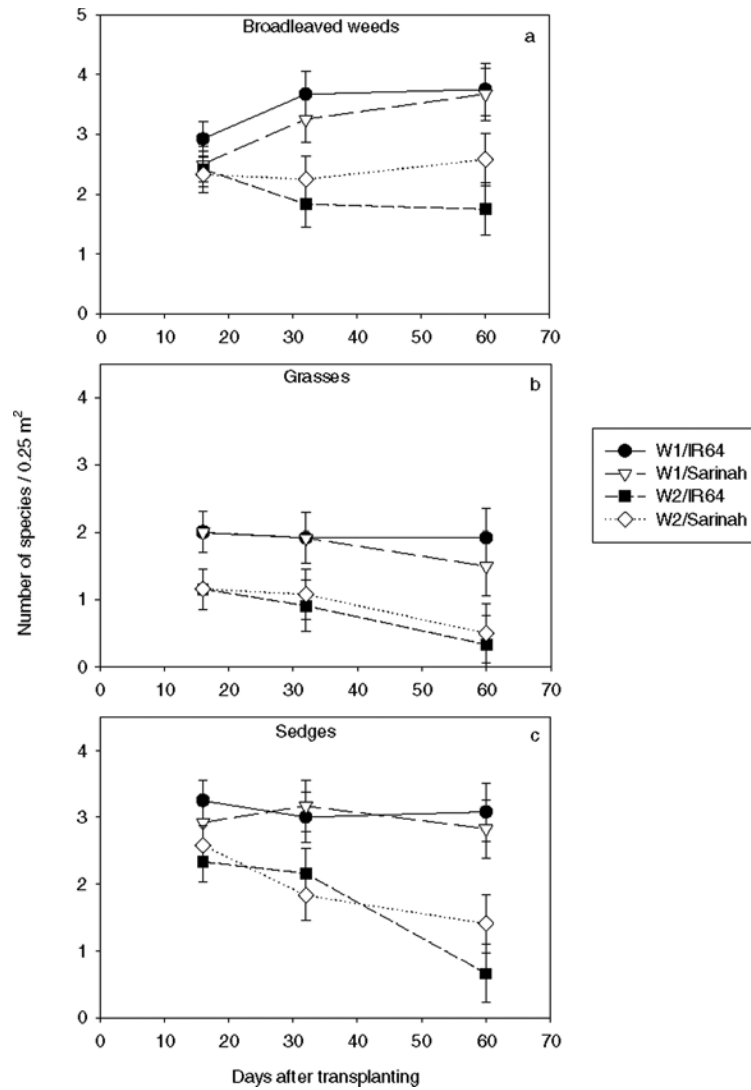
weeding had been performed at 16 DAT may have also contributed to the inconsistent effect of weeding regime at this sampling date.

By 32 DAT, just prior to the fourth weeding, the effect of weeding treatment on total weed density was significant across all sites and both cultivars (Table 4). Starker et al. (2002) reported reduced weed densities with increasing frequency of between-row cultivation in multiple rice production systems. Although total weed density was reduced through weeding at all sites at 32 DAT, the response of each weed class to between-row cultivation was less consistent. At Kerang Resik the abundance of broadleaved weeds and grasses was significantly reduced by weeding operations but variation in the response of sedges resulted in no significant difference between treatments for this class. At the Cikoneng site, grass species were more persistent and appeared to tolerate cultivation better than both sedge and broadleaved weeds. At the Rata Wangi site, only sedge density was significantly affected by weeding, though the low initial weed densities of grasses and broadleaved weeds at this site likely impacted this result. Only at the Ciherang site, was a reduction in weed density due to weeding regime observed in all weed classes and for both rice cultivars. Broadleaved weeds behaved in the most predictable way among all weed classes, exhibiting a significant reduction in density at three of the four sites following repeated weeding. There was no difference in total weed density or the density of the weed classes between the two cultivars, suggesting that the competitive cultivar had no effect on weed density. However, since rice yields are more negatively affected by high-weed biomass than by weed density, the inability of our competitive cultivar to reduce weed density should not diminish the efficacy of this management strategy given that our results also indicate that they can reduce total weed dry weight (Noda, 1973).

### *Number of Species Within Various Weed Classes*

Across all experimental sites, intensive between-row cultivation early in the season resulted in a significant reduction in the number of species present for each weed class at 32 and 60 days after transplanting (Figure 1). At the earliest sampling date (16 DAT), differences in the number of weed species were only apparent for grasses (Figure 1b). Among treatments, there was no observable difference between the two cultivars in their ability to reduce the number of species present in any of the weed classes. Since no cultivar effects were observed, the response of each weed class to the weeding treatments was generalized across both

FIGURE 1. Effect of weeding regime (W1 = natural weed growth, W2 = mechanically weeded) and rice cultivar (IR64 and Sarinah) on the species number of (a) broadleaved, (b) grass, and (c) sedge weeds. Error bars reflect the standard error of the mean.



cultivars. When no weed control measures were employed (W1), the number of broadleaved weed species increased throughout the 60 day sampling period, whereas for grasses and sedges there was little change in the number of species present (Figure 2a). Under these treatment conditions the number of grass species was significantly lower than both broadleaved weeds and sedges. Under intensive weeding operations (W2), more species in the broadleaved class withstood cultivation than did grass and sedge species, both of which displayed a more marked decline in species number throughout the season (Figure 2b). The number of sedge species, though initially high was reduced by weeding operations to low-levels statistically equivalent to the number of grass species at 60 DAT. Among broadleaved weeds which withstood tillage, namely *Ludwigia adscendens*, *Ludwigia octovalvis*, *Alternanthera sessilis*, and *Monochoria vaginalis*, all are known to grow readily from vegetative structures, such as rhizomes or stolons, in addition to germinating from seed (Caton et al., 2004). While many grass and sedge species also possess a range of viable reproductive options, the dominant species in this cropping system (e.g., *Cyperus difformis*, *Cyperus iria*, *Fimbristylus miliacea*, and *Echinochloa crus-galli*) all rely largely on seed dispersal rather than vegetative propagation for reproduction, and hence any disadvantages inherent to this particular strategy could explain the greater reductions in grass and sedge species in response to tillage (Caton et al., 2004). These comparisons, while reflecting differential tolerance to tillage among weed species, need to be considered alongside the knowledge that these scattered individuals remaining in weeded plots represent less than 1% of the biomass found in nonweeded plots and as such pose little risk to the crop.

#### ***Comparison of Species Richness, Diversity, Dominance, and Evenness***

An increase in the intensity of the weeding regime had a negative impact on most standard measures used to assess the diversity of weed communities (Table 5). Although the use of a suppressive cultivar (Sarinah) did result in a significant reduction in total weed biomass, this did not significantly affect species richness, diversity, dominance, or evenness. At 16 DAT, between-row cultivation reduced species richness (S), the most intuitive but least comprehensive of the diversity indicators. By 32 DAT, in addition to lower species richness, weed communities in the weeded treatment (W2) exhibited greater dominance by fewer species [Simpson's index, (D)] and hence less overall

FIGURE 2. Early-season changes in number of species within 3 major weed classes (● Broadleaved, ▼ Grasses, ■ Sedges) in response to two weeding regimes; (a) W1= natural weed growth, (b) W2 = mechanically weeded. Error bars reflect the standard error of the mean.

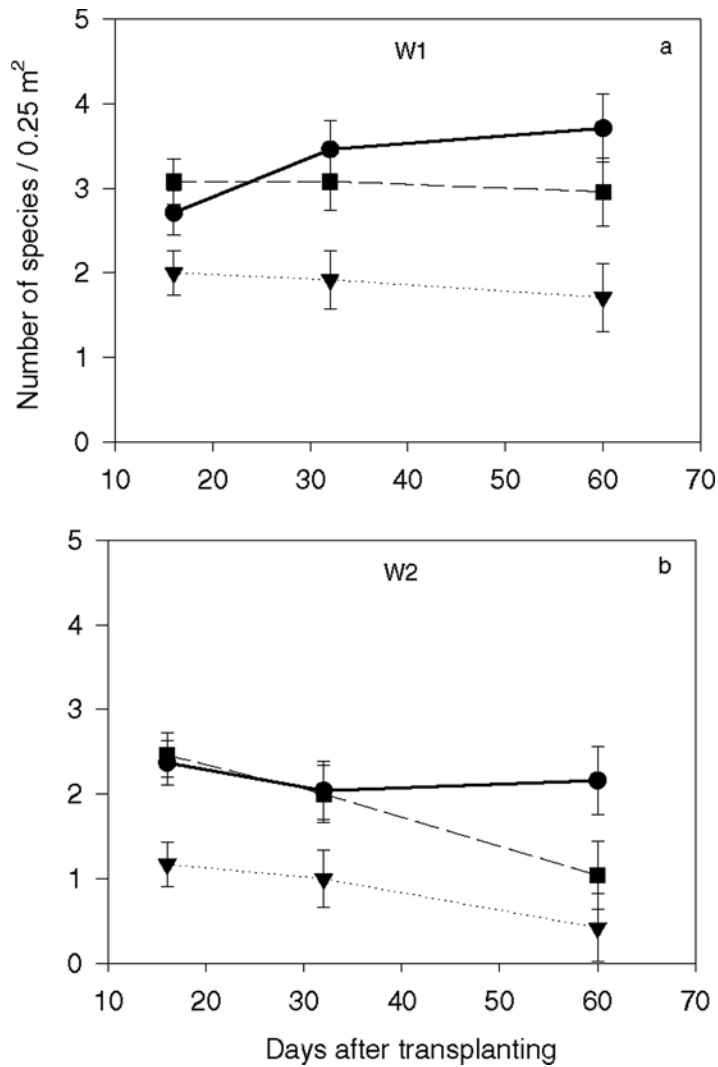


TABLE 5. Effect of weeding treatment and rice cultivar on measures of community composition across all four sites at 16, 32, and 60 days after transplanting.

| Cultivar     | Treatment | 16 DAT               |                       |                   | 32 DAT                 |                       |                      | 60 DAT                |                   |                        | Total Weed Dry Weight (0.25 m <sup>2</sup> ) |                       |                      |
|--------------|-----------|----------------------|-----------------------|-------------------|------------------------|-----------------------|----------------------|-----------------------|-------------------|------------------------|--|-----------------------|----------------------|
|              |           | Species Richness (S) | Simpson Dominance (C) | 1/C Diversity (D) | McIntosh Diversity (U) | McIntosh Evenness (E) | Species Richness (S) | Simpson Dominance (C) | 1/C Diversity (D) | McIntosh Diversity (U) |  | McIntosh Evenness (E) | Species Richness (S) |
| IR64         | W1        | 8.17                 | 0.274                 | 3.87              | 0.481                  | 1.53                  | 8.58                 | 0.219                 | 4.77              | 0.535                  | 1.51   | 8.75                  | 143.74               |
|              | W2        | 5.92                 | 0.289                 | 3.65              | 0.466                  | 1.73                  | 4.92                 | 0.393                 | 3.17              | 0.393                  | 1.76   | 2.75                  | 1.53                 |
| Sarinah      | W1        | 7.42                 | 0.287                 | 4.05              | 0.477                  | 1.59                  | 8.33                 | 0.266                 | 3.92              | 0.487                  | 1.53   | 8.00                  | 96.02                |
|              | W2        | 6.08                 | 0.307                 | 3.44              | 0.450                  | 1.70                  | 5.17                 | 0.372                 | 3.20              | 0.403                  | 2.11   | 4.50                  | 1.17                 |
| Effect T     |           | ***                  | ns                    | ns                | ns                     | *                     | ***                  | **                    | **                | **                     | *  | ***                   | ***                  |
| Effect C     |           | ns                   | ns                    | ns                | ns                     | ns                    | ns                   | ns                    | ns                | ns                     | ns   | ns                    | **                   |
| Effect T × C |           | ns                   | ns                    | ns                | ns                     | ns                    | ns                   | ns                    | ns                | ns                     | ns   | *                     | **                   |

W1 = undisturbed weed growth; W2 = mechanically weeded.

Significance level: ns = not significant ( $P > 0.05$ ), \* =  $0.05 > P > 0.01$ , \*\* =  $0.01 > P > 0.001$ , \*\*\* =  $P > 0.001$ .

Note: Each parameter was analyzed using the differences of least squares means for effects of treatment (T), cultivar (C), and interaction (T × C).

diversity [reciprocal Simpson's (1/D); McIntosh diversity (U)] as compared to the nonweeded treatment (W1). In other diverse cropping systems, higher diversity is typical of reduced tillage intensities and lower soil disturbance, in addition to reduced herbicide use (Legere et al., 2005). At both 16 and 32 days, greater species evenness [McIntosh evenness (E)] was measured in the intensively cultivated treatment. Although greater evenness is generally typical of the more diverse community, this notion assumes that the communities in question also have similar species richness (Magurran, 1988). Since this assumption is demonstrably not met in this study (i.e., W1 has significantly higher species richness than W2), the higher evenness merely reflects the uniformly low-weed densities of the few remaining species which have persisted despite intensive weeding operations. Since sampling at 60 DAT measured dry weight of resident species rather than density, species richness is the sole diversity measure presented, but further reflects continued increase in species recruitment in the nonweeded treatment and subsequent species loss in the weeded treatment.

### CONCLUSION

When left undisturbed in SRI fields, sedge weeds appear to be the most prolific weed class by virtue of their high-biomass (i.e., dry weight) production relative to the other weed classes. At the species level this was reflected by the consistently high-relative dry weights of *Fimbristylis miliacea* and *Cyperus* spp. found growing at the majority of our experimental sites. Although early season weed counts helped capture the dynamic attributes of the weed community structure and elucidate the roles different weed classes may play throughout the season, they are perhaps not as indicative of true dominance as biomass-based measurements taken at peak vegetative growth. For a given rice crop, those weed species which have accumulated the most biomass are likely to have intercepted more of the available resources which could have translated into higher grain yields at harvest (Noda, 1973). These dominant species are also more likely to have gone to seed and hence ensured their dominance in future seasons. Thus for those adopting the SRI approach, one ought to be wary of the problem that sedges are likely to pose in the medium to long term.

Intensive between-row cultivation (twice with a rotary hoe and twice with a traditional wooden weeding instrument) was an effective, albeit

laborious, strategy for weed control. The response to this weeding treatment by all weed classes was satisfactory and should serve as a confirmation of practices commonly used to varying degrees in many rice production systems including SRI (Randriamiharisoa, 2002; Sarker et al., 2002). The negative effect of intensive cultivation on the species richness and diversity of weed communities is the logical outcome of any effective weed control strategy. The response of weed communities to the use of a weed competitive cultivar was a novel element in this study. Despite the fact that there was 32.8% less weed biomass harvested from plots containing the competitive cultivar (Sarinah) as compared with the most common commercial variety (IR64), this “weed suppressive effect” was not pronounced enough to influence the composition of the weed community to a significant degree. While this may be the case from a comparative ecological standpoint, it should not discourage further examination of the potential practical benefits of using weed competitive cultivars. Competitive cultivars when coupled with reduced herbicide applications or less intensive weeding requirements may prove to be an economical and effective means for integrated weed management in SRI, in much the same way they are being used in other weed-prone rice systems (Gibson et al., 2003; Dingkuhn et al., 1999).

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