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Assessment of System of Rice Intensification (SRI) and Conventional Practices under Organic and Inorganic Management in Japan

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Abstract: The system of rice intensification (SRI) is a production system that involves the adoption of certain changes in management practices for rice cultivation that create a better growing environment for the crop. This system was compared with conventional practices and assessed under organic and inorganic management. SRI practices showed significant response in root number, number of effective tillers per hill, days to flowering and harvest index. In addition, SRI was found effective in minimizing pest and disease incidence, shortening the crop cycle, and improving plant stand. Grain yield was not different from conventional method. Except for harvest index and plant lodging percentage, there were no significant effects from management treatments. Synergistic responses were noted when SRI practices were combined with organic management for plant height, number of effective tillers per hill, days to flowering and to maturity. The improved panicle characteristics, lower plant lodging percentage and higher harvest index that ultimately led to comparable grain yields. Net returns increased approximately 1.5 times for SRI-organic management regardless of the added labor requirements for weed control. However, comparatively higher grain yield from conventional-inorganic methods underscore the need for further investigations in defining what constitutes an optimum set of practices for an SRI-organic system specifically addressing grain yield and weed management.

Key words: system of rice intensification; conventional practices; organic and inorganic management; rice growth

The system of rice intensification (SRI) involves changes in certain management practices which provide better growing conditions for rice plants than traditional practices, particularly in the rhizosphere. SRI is a set of ideas and insights that emphasize the use of younger seedlings (< 15-day-old) individually planted at wider spacing, together with the adoption of intermittent irrigation, organic fertilization and active soil aeration (Stoop et al, 2002; Uphoff, 2007). It has emerged as a set of guiding principles that can maintain high yields through stronger and healthier plants and soils while reduce reliance on external inputs. Research and demonstration plots in several tropical countries have shown SRI techniques productive, resource-saving and environmentally benign when compared to conventional rice production (Namara et al, 2004; Sato and Uphoff, 2007; Sinha and Talati, 2007).

SRI deviates from the green revolution standard that intends to increase grain yields either by improving genetic potentials of crops, making them more responsive to chemical inputs, and/or by increasing the use of external inputs (i.e., water, agro-chemicals). SRI requires neither of these considerations. Instead, it tries to maximize the potential of any existing rice genotype by changing or altering certain management practices. When the requirements are satisfied, SRI can be a high-yielding system. Many of its components have proven to be potential to increase rice yield. SRI methods have increased yields by 50%–100%, for most cultivars trialed (Uphoff, 2007).

Nevertheless, there are certain controversies over the rice yields that were reportedly achieved by using SRI method over traditional methods. Criticisms were made by Dobermann (2004), Sheehy et al (2004), and Sinclair and Cassman (2004) for the extraordinary high yields, effectiveness of SRI practices and the experimental procedures. They questioned the reported yields, pointing out the needs for clear and detailed information about experimental procedures, environmental conditions, methods of yield measurements, biomass determination, and N uptake before accepting the yield data reported from SRI-based experiments. McDonald et al (2008) also asserted that there remains inadequate evidence of a yield advantage with SRI

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over conventional methods or those considered 'best management practices' (BMP). Therefore, more rigorous and systematic research is needed to identify the potential advantages of SRI practices over those currently recommended.

More recent work on SRI has included evaluation in an expanded range of environments and impacts of several sub-components of the system. In temperate Japan, where SRI was not previously practiced, encouraging results were obtained while evaluating several sub-components. The combined use of younger seedlings (14-day-old) transplanted individually at a wider spacing (30 cm × 30 cm) and the adoption of intermittent irrigation with alternate wetting and drying intervals of 10-day until flowering were as productive as conventional practices (i.e., 7.41 t/hm^2 and 7.37 t/hm^2, respectively) (Chapagain and Yamaji, 2010). Both absolute water use savings (i.e., 28% less water used) as well as water use efficiency (i.e., 1.74 g/L water in SRI compared to 1.23 g/L in conventional method) were significantly improved with a greater plant stability (i.e., 85% less lodging).

Rice growers, in general, have relied on chemical fertilizers under the belief that they were necessary for high yields. However, achieving high yields based on the prescriptive use of fertilizers (and pesticides) may not be economically warranted. On-farm research in many Asian countries has shown that reliance on agro-chemicals was unjustified because they 1) had questionable efficacies; 2) often resulted in a negative economic return (Heong and Escalada, 1997); and 3) had detrimental effects leading to secondary pest problems (Way and Heong, 1994; Heong and Schoenly, 1998; Chaboussou, 2004). Moreover, when government subsidies for fertilizers were reduced (e.g., in Indonesia) or eliminated (e.g., in the Philippines, Nepal), small-scale rice farmers could no longer afford these inputs. In these contexts, organic SRI practices that rely primarily on-farm produced organic fertilizers and pesticides have drawn the attention of rice scientists and farming communities. On-farm demonstration plots in many tropical and sub-tropical countries have shown the benefits of SRI methods over conventional cultivation methods with respect to yield and water savings. However, only a few reports are available, which assesses the efficiency and productivity of organic SRI in tropical regions (Sato and Uphoff, 2007) with unknown reports from temperate environments. Therefore, the current study was undertaken to evaluate SRI and conventional production practices on rice crop performance and productivity in temperate Japan, as well as organic and inorganic management methods with respect to crop health and productivity.

MATERIALS AND METHODS

Study site

This study was conducted in Chiba Prefecture, Japan during the rice growing season of 2009 (May to September). The experimental site was situated at 35º52′ N and 139º59′ E, at an altitude of 11 m above mean sea level. Research was conducted under natural climatic conditions. The soil was clayey, composed of clay, silt and sand at the proportion of 59%, 28% and 13%, respectively, with fairly good soil fertility. The experimental soil had pH of 6.2 (Beckman glass electrode pH meter), organic matter of 2.89% (Walkey and Black method), total nitrogen content of 0.186% (Macro-Kjeldahl method), available phosphate 41.8 mg/kg (Olsen's method), and exchangeable potassium 160 mg/kg (Neutral normal ammonium acetate method). Soil was homogeneous across SRI and conventional plots.

Treatments

The experiment was conducted using one of the most popular rice cultivars in Japan, Koshihikari. Primary treatment components were based on results from a previous SRI experiment (Chapagain and Yamaji, 2010), published practices adopted in Indonesia (Keisuke et al, 2007; Sato and Uphoff, 2007), and common management methods for conventional rice farming in Japan (Horie et al, 2005). Research plots (25 m^2) were laid out in a factorial randomized complete block design (RCBD) with two cultivation methods (SRI and conventional) as one factor and two management methods (organic and inorganic) as the second factor. Together, these formed four treatment combinations: T_1, SRI + organic; T_2, SRI + inorganic; T_3, Conventional + organic; T_4, Conventional + inorganic (Table 1). All treatments were replicated four times and grouped by blocks. Altogether, 16 research plots were deployed. The distances were at least 50 cm between each plot and 1 m between each block to facilitate operations and to avoid treatment contamination effects across plots.

Cultivation methods

SRI: SRI plots were designed for the use of young seedlings (8-day-old), transplanted individually at a wider spacing (30 cm × 30 cm) and intermittently irrigated with alternate flooded and dry periods originally at 5-day intervals (i.e., dry for 5 d followed by flooded for 5 d and repeated) (Fig. 1-A). Eight-day-old seedlings were grown in a nursery under a protective environment and with the same level of management. Seedlings were transplanted to the SRI plots immediately from the nursery tray.

In general, intermittent irrigation was scheduled at 5-day intervals, from 10 d to 100 d after transplanting. However, irrigation was suspended for an 18-day period at 30 d after transplanting because the natural precipitation was sufficient. A simple manual measuring scale and hollow tubes up to 20 cm depth were used to measure water depth during wet and dry periods, respectively. Water level was maintained up to 1.5 cm during the flooded period while fields were allowed to drain naturally during dry periods until the water table reached 10–12 cm below surface before resumption of irrigation. The irrigation intervals were determined based on the water level, sometimes sooner (when water level fell below 10–12 cm earlier) and sometimes later (if it took a longer time to fall below 10–12 cm). Therefore, the final schedule was developed with irrigation intervals starting 4–18 d of dry periods (Fig. 1-A). The plots were equipped with a pipe irrigation system with proper water inlet and outlet devices for timely irrigation and drainage. Flooding occurred in the evening (if there was no rain during the day) for the first day of the cycle while the water was drained in the morning of the first day of the dry period.

Conventional: The conventional system represented the conventional practices in Chiba, Japan and included the use of 22-day-old seedlings transplanted in a clump of 4 seedlings per hill at relatively close spacing (30 cm × 18 cm). Plots were equipped with devices for continuous irrigation (up to 5–6 cm depth) throughout the growing season. A mid-summer drainage was allowed at 81−90 d after transplanting as the general practices in the local community. External irrigation stopped and the field water drained completely during the summer drainage period (Fig. 1-B).

Management methods

Organic: Experimental fields selected for this

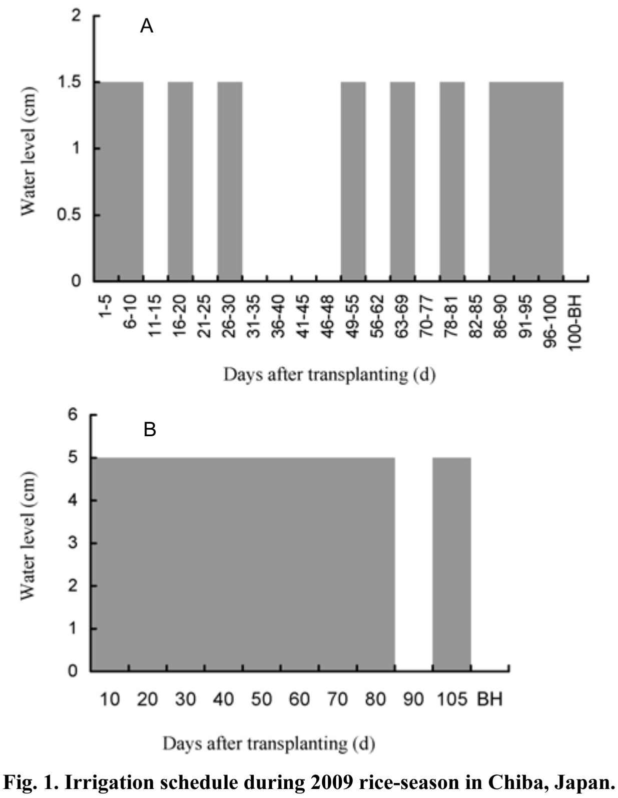

Fig. 1. Irrigation schedule during 2009 rice-season in Chiba, Japan.
A, Under the system of rice intensification (SRI); B, Under the conventional system. BH, Before harvest.

Table 1. Treatment details during 2009 rice-season in Chiba, Japan.

Cultivation method	Management method	Treatment combination	Age of seedlings (d)	No. of seedlings per hill	Spacing (cm × cm)	Plant density (m^2)
SRI	Organic	SRI-organic (T_1)	8	1	30 × 30	11 (11)
	Inorganic	SRI-inorganic (T_2)	8	1	30 × 30	11 (11)
Conventional	Organic	Conventional-organic (T_3)	22	4	30 × 18	72 (18)
	Inorganic	Conventional-inorganic (T_4)	22	4	30 × 18	72 (18)

SRI, System of rice intensification.
Values in parenthesis under the plant density column are number of hill per unit area (m^2) in respective plots.

experiment were used for rice cultivation in previous years with minimal use of fertilizers and pesticides. However, for last three years, there was no use of chemically synthesized inputs except for those permitted under Japanese organic regulations. We used Bio Organic, a solid organic fertilizer manufactured and supplied by the Blue Trading Company Ltd., Osaka, Japan, which contains 7% moisture, pH 4.8, 4.3% nitrogen (N), 1.07% potassium (K_2O), and a carbon to nitrogen ratio (C/N) of 10. It was applied once at 1 t/hm^2 (1.5 kg/plot) after draining and the completion of puddling and leveling the field. Weed management consisted of three manual cultivations at 20, 35 and 50 d after transplanting. No additional chemical fertilizers or pesticides were used in the organic plots.

Inorganic: Fertilization management used urea, single super phosphate (SSP), and potassium chloride (KCl) at the respective rates of N 40 kg/hm^2, P_2O_5 60 kg/hm^2 and K_2O 80 kg/hm^2. Phosphorus and K were applied at the time of final plot preparation or puddling whereas N was applied at three installments, i.e., 50% was applied as a base dose during transplanting, 25% top-dressed at tillering stage (40 d after transplanting), and 25% at panicle initiation stage (75 d after transplanting). This rate was calculated as per the prefectural recommendation for Koshihikari in Chiba, Japan. The pre-emergence herbicides Bensulfuron-methyl (BSM) and mefenacet were applied once at 30 kg/hm^2 at 5 d after transplanting. No additional pesticides or fungicides were used in the inorganic plots as the pest pressures were below the economic threshold level, i.e., less than 10% of leaf damage during the vegetative stage or 5% of flag-leaf damage at the flowering stage, as suggested by Samiayyan et al (2010).

Data collection and analysis

Plant-based parameters

Twenty hills (>1 m^2) were randomly sampled from the central area in each experimental unit for crop measurements. Observations were taken at 20-day intervals from 10 d after transplanting. Parameters measured included plant height (from soil surface to the tip of apical leaf), number of tillers per plant, number of effective tillers (panicles) per plant (and per m^2), days to flowering, days to harvest, and grain and straw yields (g/hill and kg/m^2). Harvest occurred when grain moisture (measured with grain moisture meter, Model MD7822, Shenzhen Sanpo Instrument Company Ltd., China) reached 19%–21% in the early afternoon during dry weather conditions (Have, 1967). Grain color was also a determinant of maturity and considered ready for harvest when 80% of the panicles in the sample plants were straw-colored, and the grains in the lower portions of the panicle were at the hard-dough stage.

In addition, plots were rated for lodging resistance before harvest and scored on a scale of 0–10 (0 for all erect plants and 10 for complete lodging). Also, the angle of lodging of an individual plant (or tiller within a hill) was also assessed. Plants (or tillers) that were completely bent down to the ground (60º to 90º) with all panicles touching the soil surface were considered ‘complete lodging’ whereas plants up to 60º lodging without having panicles contacting the ground surface were considered ‘partial lodging’. The scores were subjected to mean calculation and later transformed into percentage assuming 1 equals 10%.

Crop management parameters

Weed populations were characterized by species composition, and the time required for their control. General observations were made on the type of weeds that infested SRI and conventional plots. In addition, insect pest and disease pressures were quantitatively observed and assessed with regard to types and nature of damage. Pest density and extent of damage were calculated for the larvae of rice leaf folder (*Cnaphalocrocis medinalis*), which was a major pest that appeared during 2009 season, by counting the number of larvae and calculating the percentage of damaged leaves during the early vegetative stage (25 to 45 d after transplanting), a peak period of infestation as suggested by Chapagain and Yamaji (2010). These data were used to determine the economic threshold level as suggested by Samiayyan et al (2010) to determine the frequency and timing of subsequent pesticide applications.

Crop budgeting

Production costs measured included labor inputs (e.g., transplanting, water management, weed control, fertilizer and herbicide application), costs of mechanical power (e.g., field preparation and harvesting), seed/seedlings, chemical inputs (i.e., chemical fertilizers and herbicides), and organic fertilizers. Water is not a major issue in Japanese rice cultivation, however, pricing was done for irrigation water considering reductions and savings of 30% water in SRI plots (Chapagain and Yamaji, 2010). The average economic value of irrigation water in conventional paddy fields [53 000 yen/(hm^2·year) i.e., 630 US$/(hm^2·year)] (Kunimitsu, 2006) was used for calculation. Pricing was also done for crop yield (i.e., grain) based on their value at a local market, with a general comparison made in terms of input-output analysis.

Statistical Analysis

Data were compiled and subjected to mean calculation and analysis of variance using Microsoft Excel and MSTAT-C software. Mean separation was done by LSD, and simple correlations were run between selected parameters using Statistical Package for Social Science (SPSS) software.

RESULTS AND DISCUSSION

Plant-based parameters

Data summaries are presented in Table 2. SRI practices promoted a significant and positive response in a number of vegetative and reproductive characteristics. Specifically, number of roots, number of effective tillers in a hill, days to flowering and days to harvest, plant lodging percentage, and harvest index were positively influenced by SRI method. However, parameters including number of effective tillers per m^2, grain yield, and straw yield were significantly greater in the conventional plots.

SRI method exhibited significant effects on number of roots in a hill with 330 roots measured compared to 252 in conventional at 70 d after transplanting. Several general observations on plant performance across SRI and conventional plots included a higher proportion of whitish (alive) vs. black (decaying) roots (21:10 and 10:13 for SRI and conventional plots, respectively), larger stem diameters and darker green foliage that appeared to be more productive. There was no significant difference for the number of leaves per plant, but a clear difference in the leaf color and width (wider leaves) that remained green until grain filling and maturity in SRI treatments. Number of tillers in a hill was also positively affected by SRI management (20.5 compared to 16.7 in conventional plot), but the number of tillers per unit area (m^2) was negatively affected (228 compared to 310 in conventional plots), which could be due to the effects of plant density during transplanting.

Table 2. Effects of SRI and conventional methods under organic and inorganic management during 2009 rice-season in Chiba, Japan.

Treatment composition	PH (cm)	No. of roots	ETH	ETM	DTF (d)	DTH (d)	GY (t/hm^2)	SY (t/hm^2)	HI (%)	PLP (%)
Cultivation method										
SRI	119.4	330	20.5	227.5	84 (76)	128 (120)	6.3	4.9	54.0	10
Conventional	115.4	252	16.7	309.5	94 (72)	136 (114)	6.7	6.5	52.6	55
SE (±)	2.91	15.48	1.73	11.16	2.52	3.01	0.24	0.28	1.92	8.56
$LSD_{0.05}$	NS	30.95	3.45	22.35	5.05	6.04	NS	0.56	NS	17.12
Fertilizer management										
Organic	116.6	295	18.0	259	89 (74)	132 (117)	6.5	5.6	56.0	9
Inorganic	118.3	287	19.2	278	89 (74)	132 (117)	6.4	5.8	50.6	56
SE (±)	3.06	14.08	1.89	10.56	2.32	2.84	0.22	0.25	2.06	7.92
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	4.12	15.85
Interaction effects										
SRI-organic	120.0 a	328 a	20.2 a	224 c	84 b (76)	128 b (120)	6.6 a	4.8 b	57.8 a	0 b
SRI-inorganic	118.8 a	332 a	20.8 a	231 c	84 b (76)	128 b (120)	5.9 b	5.0 b	50.2 b	20 b
Conventional-organic	113.1 a	262 b	15.9 b	294 b	94 a (72)	136 a (114)	6.5 ab	6.4 a	54.2 ab	20 b
Conventional-inorganic	117.8 a	242 b	17.6 b	325 a	94 a (72)	136 a (114)	6.8 a	6.6 a	50.9 b	90 a
SE (±)	4.37	18.76	1.98	13.39	2.91	3.56	0.32	0.36	2.82	10.67
$LSD_{0.05}$	NS	37.52	3.95	26.8	5.8	7.12	0.65	0.72	5.65	21.35

PH, Plant height; ETH, No. of effective tillers in a hill; ETM, No. of effective tillers per unit area (m^2); DTF, Days to flowering (after seeding); DTH, Days to harvest (after seeding); GY, Grain yield; SY, Straw yield; HI, Harvest index; PLP, Plant lodging percentage. NS, Not significant.

Data in parenthesis under the DTF and DTH columns are days after transplanting. The same lowercase letters behind the data indicate no significant difference among the interaction effects.

A significant response of SRI management was shown in reducing the days to flowering (by 10 d) and days to harvest (by 8 d) while accounting the age of transplanted seedlings. On average, SRI plots began flowering at 84 d after sowing and harvested after 128 d compared to 94 d and 136 d for flowering and harvest, respectively, in conventional plots (Table 2). However, the time to flowering (74 d compared to 72 d in conventional plots) and harvest (120 d compared to 114 d in conventional plots) was slightly longer under SRI management when counting days after transplanting.

Grain yield was marginally greater under conventional method (6.7 t/hm^2) than under SRI management (6.3 t/hm^2), although not statistically significant (Table 2). However, straw yield under conventional method was significantly greater (6.5 t/hm^2) than under SRI (4.9 t/hm^2), thereby lowering the harvest index for conventional management (Table 2). As the number of tillers per unit area was significantly higher in conventional plots, plant biomass was greater under conventional management. In other words, SRI plants produced greater economical yield compared to conventional management.

Except for the harvest index and plant lodging percentage, no significant effects of organic management were observed. Organic plots were associated with greater harvest index (56% compared to 51% in inorganic management) with 45% less plant lodging percentage as compared to inorganic management.

Synergistic responses were observed between SRI practices and organic management. SRI-organic plots displayed enhanced responses for several vegetative and reproductive characteristics (Table 2). Except for the number of effective tillers (panicles) per unit area and straw yield, all other parameters were positively influenced in this combined treatment. Plant height at harvest, root number, number of effective tillers in a hill, grain yield and harvest index were significantly improved under SRI-organic management (Table 2). SRI-inorganic management also possessed similar values except for grain yield (5.9 t/hm^2 compared to 6.6 t/hm^2 in SRI-organic) and harvest index (50% compared to 58% in SRI-organic). As there was no manual weeding in SRI-inorganic plots, the formation of a hard surface layer, as a result of alternate wetting and drying cycles, limited crop growth at 60 d after transplanting, resulting in reduced yields. Conventional-inorganic plots produced the highest yields (6.8 t/hm^2) followed by SRI-organic (6.6 t/hm^2), and then by conventional-organic (6.5 t/hm^2) with the lowest yield from the SRI-inorganic plots (5.9 t/hm^2) (Table 2).

The observed effects of SRI management on vegetative and yield-associated traits are supported by previous research. Chapagain and Yamaji (2010) reported that SRI management promoted better root growth, greater number of effective tillers in a hill, longer panicle length, and greater number of filled grains per panicle over conventional management. They further pointed out the greater development of healthy, white and functional roots in SRI management that supports larger stems and more efficient leaves for photosynthate production.

Kirk and Solivas (1997) also reported that when rice plants were grown in continuously saturated paddy soils, their growth was diminished and their function compromised by premature decay of the root system. They also observed that about 75% of rice roots remained in the top 6 cm of soil where oxygen was more available. Kar et al (1974) found that over 75% of rice roots were degraded at the beginning of reproductive stage when the soil was kept continuously flooded. Iida et al (1990) also found a decreased percentage of decayed roots with reduced flooding.

The SRI effects on enhanced tillering and earlier flowering were also supported by the findings of Udaykumar (2005), Vijayakumar et al (2006) and Krishna et al (2008), who achieved greater yields and better grain quality in SRI management compared to conventional methods. The favorable effect of SRI might be due to more efficient utilization of resources as a result of less inter- and intra-space competition.

Crop management parameters

Pest and disease pressures

The adoption of SRI management positively affected pest and disease pressures in rice cultivation. In both SRI-organic and SRI-inorganic plots, no significant pest or disease infestations occurred throughout the experimental period. However, conventional plots, both organic and inorganic, exhibited significant infestations of rice leaf folder larvae (*C. medinalis*) at 25–35 d after transplanting (Fig. 2). Larvae counted at 27 d after transplanting on conventional plots revealed small population differences between organic and inorganic plots. Only one plant in the SRI-organic plots suffered from seedling blight disease caused by pathogenic fungi (*Fusarium* spp.). Since larvae populations and disease problems were below economic thresholds in all plots, no pesticides or fungicides were applied.

The low pest incidence in SRI plots appeared to be associated with the intermittent irrigation schedule and reduced plant density, especially during the peak period of infection. The larvae of rice leaf folder

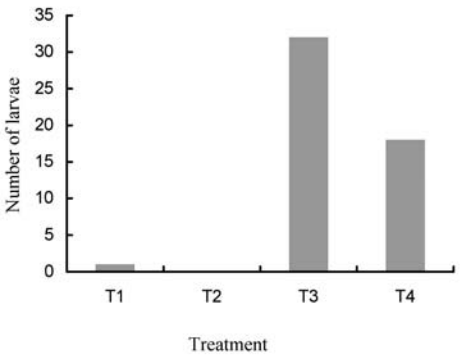

Fig. 2. Larvae of rice leaf folder as affected by management conditions at 27 d after transplanting.

T_1, SRI-organic; T_2, SRI-inorganic; T_3, Conventional-organic; T_4, Conventional-inorganic.

required a sufficient number of leaves to feed upon, thereby reducing productive leaf area. Therefore, the fewer number of leaves present during the peak period of infestation could limit pest activity in SRI plots. This is supported by the findings of Chapagain and Yamaji (2010), and Chaboussou (2004) that plants under SRI management and organic fertilization were more resistant to losses from pests or diseases, thereby requiring less chemical intervention.

Weed Pressure

Weed management under organic treatments was more labor-intensive than in inorganic treatments. The most common weeds were *Cyperus rotundus* L., a narrow-leaved weed species commonly in SRI-organic plots and *Sagittaria* spp., a broad-leaved weed species commonly found in the conventional-organic plots. Infestation was the most severe at 35 d after transplanting (second weeding) and 50 d after transplanting (third weeding), thereby requiring more labor than during the first weeding (20 d after transplanting). In general, the labor input required in SRI-organic plots was double (90 man·d/hm^2) that in conventional-inorganic plots (45 man·d/hm^2) (Table 3), and was primarily affected by the weeding requirement (50 man·d/hm^2). Inorganic plots, either SRI or conventional, did not experience significant weed pressure at any time

Table 3. Crop budget analyses for SRI versus conventional rice farming using organic and inorganic management during 2009 rice-season in Chiba, Japan.

Input	Unit cost (US$) [a]	SRI-organic		Conventional-organic		SRI-inorganic		Conventional-inorganic	
		Quantity	Amount	Quantity	Amount	Quantity	Amount	Quantity	Amount
A. Inputs (per hectare)									
Labor									
Human (man·d)	42	90	3 780	60	2 520	60	2 520	45	1 890
Mechanical (h)	36	12	432	12	432	12	432	12	432
Material									
Seed (kg)	2.4	5	12	45	108	5	12	45	108
Chemical									
Nitrogen (kg)	9.5	0	0	0	0	40	380	40	380
Phosphorus (kg)	9.5	0	0	0	0	60	570	60	570
Potassium (kg)	10.0	0	0	0	0	80	800	80	800
Herbicide (kg)	9.5	0	0	0	0	30	285	20	285
Organic fertilizer (kg)	0.6	1000	600	1 000	600	0	0	0	0
Water cost	lump-sum		440		630		440		630
Miscellaneous	lump-sum		238		238		238		238
Total cost (US$)			5 502		4 528		5 677		5 333
Cost (US$/kg)			0.83		0.70		0.95		0.78
B. Returns (per hectare)									
Grain (kg)	Organic: 2.4 Inorganic:1.8	6590	15 816	6 490	15 576	5 900	10 620	6840	12 312
Returns (US$)			15 816		15 576		10 620		12 312
Net returns per hectare (B-A)			10 314		11 048		4 943		6 979

[a] 1 US$ = 84 Japanese Yen.

during the experiment and therefore requiring no additional time for weeding. The single application of pre-emergence herbicide was effective in controlling weeds. However, inorganic plots, either SRI or conventional, were also observed with fewer *C. rotundus* and *Sagittaria* spp., respectively at 60 d after transplanting, when the plant canopy completely shaded the soil surface.

Some disagreements concerning the measurement of labor for weed management appeared to be reasonable with SRI practices. Association-Tefy-Saina (1995) and Rakotomalala (1997) reported that SRI required approximately 38%–54% more labor than conventional methods. According to Rakotomalala (1997), 62% of the extra labor was needed for weed management while 17% for transplanting. However, it is worth noting that labor requirements under SRI management in the first or second year are likely to be greater than in later years once the management practices have been mastered. In Madagascar, a comparison over five years found that SRI was labor-saving by year 4 compared to years 1−3 (Barrett et al, 2004).

Effects on crop stand/plant lodging

There were significant differences among treatment combinations for plant lodging percentage (Table 2). SRI treatments averaged only 10% lodging, and all characterized as partial lodging, whereas conventional treatments averaged 55% lodging, and 47% of which was complete lodging. Similar to cultivation treatments, management treatments also displayed differences with organic plots displaying 9% lodging and inorganic plots displaying 56% lodging. In addition, there were significant treatment interactions. The range in lodging percentages was from a low of 0% in the SRI-organic treatment to the high of 90% in the conventional-inorganic treatment with the remaining two treatments equal at 20%. A positive and strong correlation (r^2 = 0.74) was found between plant stand and the number of healthy roots. In addition, a positive but weak correlation (r^2 = 0.46) was found between grain production and plant lodging. This result is supported by the findings of Chapagain and Yamaji (2010) who reported 93% lodged plants in conventional management compared to 9% in SRI. One possible reason could be the premature decay of rice roots at the beginning of the reproductive stage when the soil is kept continuously flooded (Kar et al, 1974). This was clearly visible in terms of increased black or decayed roots in plants grown under conventional flooding (Iida et al, 1990; Chapagain and Yamaji, 2010).

Crop budget

A summation of crop input costs was made for the 2009 rice growing season in order to compare the production methods (Table 3). Calculations were done considering differences in production and management costs in Japan. Per unit production costs for paddy cultivation under SRI-organic was slightly higher than in conventional-inorganic with 0.83 US$/kg of grain produced and 0.78 US$/kg, respectively. Almost 68% of total costs involved in SRI-organic management were governed by labor, with most attributed to weed management (56%). Moreover, the production costs under organic management averaged 0.77 US$/kg of grain compared to 0.87 US$/kg in inorganic management. The share of agro-chemicals (i.e., fertilizers and herbicides) was 38% and 36% of total costs in conventional-inorganic and SRI-inorganic plots, respectively.

Overall, the production costs for SRI plots were comparatively higher (0.89 US$/kg) compared to the conventional plots (0.74 US$/kg). Despite the reduced material costs of SRI plots (i.e., 80% reduction in seed costs and 70% reduction in fertilizers and pesticides costs), the overall production costs were still higher as the costs of increased labor coupled with comparatively lower yields. However, net returns increased by about 1.48 times for SRI-organic compared to conventional-inorganic methods and were associated with a price premium for organic rice (Table 3).

Yields under SRI management were typically comparable to conventional management, but input costs (e.g., water, synthetic fertilizers and pesticides) are significantly lower. Kunimitsu (2006) reported that the economic value of irrigation water for paddy fields ranges from 0.4 to 0.65 US$/m^3, depending on the location of the paddy field. Similarly, research from the International Water Management Institute (IWMI) has shown that the value of water consumed in agriculture ranges from 0.05 to 0.90 US$/m^3 (Perry, 2001). Therefore, SRI can greatly increase net benefits as it saves approximately 25%–50% water over conventional production (Randriamiharisoa and Uphoff, 2002; Chapagain and Yamaji, 2010), thereby reducing production costs under water-scarce conditions. As SRI farmers spend less money on inputs, they reduce their financial risk on crop production, and the negative impact of agro-chemicals on the environments. Evaluations done by Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) and IWMI have calculated that financial risk farmers are reduced with SRI (Anthofer, 2004; Namara et al, 2004), and concluded SRI as a valuable system with respect to a farmer's enterprise budget.

SUMMARY AND CONCLUSION

SRI practices compared with conventional methods showed some notable benefits including response in root number (>30%), number of effective tillers in a hill (>25%), days to flowering (10 d earlier while counting days after seeding), and harvest index. In addition, SRI practices were effective in minimizing the incidence of rice leaf folder (1 larvae compared with 25 in conventional cultivation), shortening the rice crop cycle (by 8 d), and improving plant stand (10% lodging compared with 55% in conventional cultivation). However, grain yield was not significantly different between cultivation methods (6.3 t/hm^2 vs. 6.7 t/hm^2 from conventional method). Except for harvest index (56% compared to 51% from inorganic management) and plant lodging percentage (9% compared to 56% in inorganic management), no significant effects were observed from the different management treatments.

Synergistic responses were observed when SRI practices were combined with organic management that ultimately led to comparable grain yields (6.6 t/hm^2 compared to 6.8 t/hm^2 from conventional-inorganic management). The effect of SRI-organic was more pronounced on lodging (no lodging compared with 90% lodging in conventional-inorganic management) and harvest index (58% compared to 50% in conventional-inorganic management). Net returns also increased approximately 1.48 times for SRI-organic management despite of the added labor requirement (56% of total costs) for weed control. However, comparatively better grain yields from conventional-inorganic methods underscore the need for further investigations in defining what constitutes an optimum set of practices for SRI-organic systems specifically addressing the nutrient requirements, grain yields and weed management. Once farmers learn that they can reduce their seed requirement, water requirement, production costs, and perhaps labor requirements, while maintaining or increasing yields, SRI methods are poised to become more widely adopted.

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