

# **A Critical Assessment of the Importance of Seedling Age in the System of Rice Intensification (SRI) in Eastern India**

Debal Deb<sup>1</sup>, Jörg Lässig<sup>2</sup> and Marius Kloft<sup>3</sup>

<sup>1</sup>Centre for Interdisciplinary Studies, Kolkata, India

<sup>2</sup>Institute of Computational Science, Università della Svizzera italiana, Switzerland

<sup>3</sup>Statistical Machine Learning Laboratory, TU Berlin, Germany

## **Abstract**

A survey of SRI-related literature indicates that different authors have drawn conflicting inferences about rice yield performances under the SRI, chiefly because of the SRI methodology has been variously advocated, interpreted, and implemented in the field, using different rice varieties, seedling ages at transplantation, cultivation seasons, and nutrient management regimes. In particular, the SRI method of single-seedling transplantation (SST) has potential economic advantage due to reduced seed costs, but it is not clear whether SST is an effective management strategy across a range of seedling ages, and if there is any specific seedling age that is optimal for yield improvement of a given rice variety. This is an important consideration in rainfed ecosystems where variable rainfall patterns and lack of controlled irrigation make it difficult to reliably transplant at a specific seedling age as recommended for the SRI. We conducted a 5 year-long experiment on a rain-fed organic farm, using a short-duration upland and a medium-duration lowland landrace, following the SRI methodology. Rice seedlings of different ages (6, 10, 14, 18, 28 days after establishment) were transplanted at 25 cm x 25 cm spacing, in three replicated plots. The performance for each landrace was examined with respect to productive tillers, panicle density, total grain counts per hill, and grain yield per unit area. Performances of seedlings of different ages were compared to that of control plots that employed all SRI practices, with the exception that 28 day-old seedlings were transplanted with 3 seedlings per hill. The results indicate that (1) the SRI can improve mean panicle density if seedling age  $\leq 18$  days, but that responses differ between varieties; (2) the number of productive tillers per hill is significantly less in SST than that of multiple seedling transplants (MST) of 28 day-old seedlings of both upland and lowland varieties; (3) the total grain numbers per hill of the lowland variety is significantly greater for 14 day-old SST than 28 day-old MST; (4) the grain yield per unit area from young SRI transplants is significantly greater than that from 28 day-old MST for the lowland variety, although the magnitude of the improvement was small; (5) for the upland variety, grain yields declined with the oldest seedlings, but planting multiple seedlings per hill made the yield of oldest transplants on par with that of younger seedlings planted singly. Our findings suggest that transplanting younger seedlings under SRI management may not necessarily enhance grain yields.

## 1 Introduction

2  
3 The system of rice intensification (SRI) has evoked considerable interest among agronomists over the  
4 past few years, and posed interesting research questions in plant physiology. The SRI is essentially  
5 comprised by the following methodological components (Stoop *et al.* 2002; Uphoff 2003; McDonald *et*  
6 *al.* 2008):

- 7 • Shallow (1-2 cm) transplanting of young (< 16 day-old, or before the 4th phyllochron) seedlings  
8 without delay into a moist but not flooded seedbed
- 9 • Transplanting of single seedlings at wide (25 cm x 25 cm to 30 cm x 30 cm) spacing (with plant  
10 density not exceeding 16 m<sup>-2</sup>)
- 11 • Alternation of wetting and drying of the field during vegetative growth
- 12 • Low nutrient input, in an organic form (*e.g.* compost).

13 This technique drastically reduces seed and water requirement but increases the growth of weeds, which  
14 need frequent removal. Nevertheless, SRI seems to have several advantages for farm economies, in terms  
15 of substantial saving on the expenditure on seeds, nutrient inputs, and water (Uphoff *et al.* 2002, Uphoff  
16 2003), and is thus considered to be superior in resource-poor farms to the conventional practice  
17 (Dobermann 2004). The higher labor cost for weed control is reported to be more than offset by  
18 significantly greater grain output (Uphoff 2003; Nissanka and Bandara 2004).

19  
20 Although claims of miraculous yields (*e.g.*, 15-23 t ha<sup>-1</sup> by Rafaralahy 2002) have been critiqued (Sheehy  
21 *et al.* 2004; Dobermann 2004; Horie *et al.* 2005), the overall effect of SRI on grain output, reported from  
22 over 20 countries—from Cuba to China and from Gambia to South Asia—is impressive (Stoop *et al.*  
23 2002; Uphoff 2003; Uphoff *et al.* 2008). Most studies report profuse emergence of tillers from each  
24 seedling after transplanting, and a remarkable increase in grain yield, which constitutes a “standard  
25 claim” of SRI proponents. However, in recent years, substantial skepticism about the standard claim has  
26 surfaced among crop scientists. A few researchers have found no significant difference in rice yield  
27 between SRI and conventional best practices (Sinclair and Cassman 2004; Sheehy *et al.* 2004; McDonald  
28 *et al.* 2006, 2008), and assigned the reports of high grain output from SRI to “unconfirmed field  
29 observations” (UFOs) (Sinclair and Cassman, 2004) and/or measurement error (Sheehy *et al.* 2004,  
30 2005). Although this critique has been contested on methodological and empirical grounds (Uphoff *et al.*  
31 2008; Thakur *et al.* 2010), it seems that different standards of experiments adopted by different  
32 researchers pose a formidable methodological debacle to establishing conclusive evidence in favor of an  
33 SRI advantage. Furthermore, some of the studies examining SRI effects on rice yield did not strictly  
34 follow SRI methodologies, as their SRI treatments included transplanting of 2 seedlings per hill (Latif *et*  
35 *al.* 2005); higher seedling density ( $\geq 25\text{m}^{-2}$ ) at transplanting (Pasuquin *et al.* 2008; Senthilkumar *et al.*  
36 2008; Thakur *et al.* 2009); use of synthetic fertilizers without compost (Sinha and Talati 2007;  
37 Senthilkumar *et al.* 2008; Pasuquin *et al.* 2008; Mahender Kumar *et al.* 2010) or with compost (Thakur *et*

1 *al.* 2009). Overall, the published studies do not seem to tease out the different plausible factors  
2 contributing to grain yield increase, and raise several methodological questions that still remain  
3 inadequately answered:

- 4 • Does single seedling transplanting (SST) alone, regardless of, or in combination with young ages  
5 of seedlings, have any significant effect on the proportion of productive (panicle-bearing) tillers?
- 6 • What is the optimum seedling age at transplanting to achieve the best grain yield?
- 7 • Which type of rice genotype is the most likely to significantly improve yield under SRI?

8  
9 The first question arises because no controlled experiment has established the effect of single-seedling  
10 transplanting (SST – an essential component of SRI) vs conventional multiple-seedling transplanting  
11 (MST) on yield components for a specific type of rice cultivar. Regarding the second question, most  
12 researchers have conducted experiments with an arbitrarily selected seedling age at transplanting between  
13 8 days and 16 days. For example, in Sumatra, McHugh (2002) recorded the highest yields from 10 day-  
14 old transplants, while Makarim *et al.* (2002) reported that 15-day-old transplants out-yielded 21 day-old  
15 transplants. Krishna and Biradarpatil (2009) observed higher grain yields with 12 day-old transplants than  
16 8 day-, 16 day- and 25 day-old transplants. In Thailand, 12 day-old transplants consistently out-yielded 30  
17 day-old transplants (Mishra and Salokhe 2008). In India, Mahender Kumar *et al.* (2010) and Thakur *et al.*  
18 (2010) both recorded higher yields from SRI plots planted to 12 day-old seedlings compared to 25 day-  
19 old transplants. Thus, taken together, it is hardly possible to ascertain whether transplanting at a particular  
20 seedling age (say 12 days) is likely to increase either productive tillers or grain yields compared to  
21 another seedling age (say 10 or 16 days) in all countries.

22  
23 The third point at issue is that different investigators in different countries have employed different rice  
24 varieties; neither the critical evaluations of SRI (e.g. Sheehy *et al.* 2004) use the same cultivars as those  
25 used in the studies they contest, nor do they compare yield performances of different cultivars under the  
26 same experimental conditions. Published studies have almost always examined photoperiod-insensitive  
27 cultivars, and all of these are modern hybrid or elite “high-yielding” varieties, grown on irrigated farms.  
28 The only exception we found is a study by Tsujimoto *et al.* (2009), where local and locally improved  
29 varieties were used, but their comparison of the SRI and conventional farming systems involved different  
30 varieties on different study sites. Thus, such studies fail to make it clear if the rice yield increase or  
31 decrease was influenced by the selected rice genotype compared to others.

32  
33 The selection of the cultivar is also important in SRI testing because different rice varieties have different  
34 degrees of tolerance to water stress. Upland-adapted local landraces tend to be more water stress-tolerant  
35 than modern hybrids and the landraces adapted to flooded soils (Deb 2005; Atlin 2006). Indeed,  
36 moderately drought-tolerant cultivars are known to be appropriate for aerobic rice cultivation in Asia  
37 (Atlin *et al.* 2006; Farooq *et al.* 2009). It is therefore not clear if the less water demand of rice plants

1 reported in SRI literature is a consequence of the selection of cultivars that are adapted to water stress.

2  
3 Thus, amidst the wide range of experimental materials and standards employed in SRI research in  
4 different countries (McDonald *et al.* 2008; Stoop *et al.* 2009), there is no published literature to enable  
5 one to compare grain yields between different rice genotypes and seedling ages on SRI farms. With an  
6 aim to bridge this gap of understanding, we undertook the present study over a period of 5 years, using  
7 two different rice landraces and different seedling ages at transplanting. We compare the effects of  
8 seedling age at transplanting on tillering abilities, number of grains per panicle (panicle density), grain  
9 counts per hill, and yield per unit of land area for two landraces in rain-fed condition.

## 12 **Materials and Methods**

### 14 *Study Site and Plot Management*

15  
16 Experiments were conducted from 2005 to 2009 on 1.2 acre of Basudha farm ([www.cintdis.org/basudha](http://www.cintdis.org/basudha)),  
17 located in the district of Bankura, West Bengal, India (23°12' 25.6" N, 87°16' 54.3" E). The area is  
18 characterized by undulated lateritic terrain with contiguous dry upland and lowland paddy fields.

19  
20 Basudha farm's topsoil is sandy clay (44%, 52% clay, 4% silt), on oxisol substrate. Soil samples were  
21 collected at the end of the 1994-95 cropping cycle, and tested using standard methods cited in  
22 Government of India (2011). The farm soil has a mean pH of 6.1, and E.C. 0.16 mS cm<sup>-1</sup>. The organic  
23 matter content (Walkley-Black) of the soil was 3.3%, available N 226 kg ha<sup>-1</sup>, exchangeable K (NH<sub>4</sub>O-  
24 Acetate) 94 kg ha<sup>-1</sup>, and available P (Olsen) 3.8 mg kg<sup>-1</sup>.

25  
26 The farm received no synthetic agrochemicals for the past 15 years. At the onset of each cropping cycle,  
27 all plots and nursery beds were treated with composted cattle manure (equivalent N content 12 g m<sup>-2</sup>) at  
28 400 g m<sup>-2</sup>, 80 g m<sup>-2</sup> of green manure, and 20 g m<sup>-2</sup> of rock phosphate (20% P<sub>2</sub>O<sub>5</sub>), inoculated with  
29 phosphorus solubilizing bacteria (*Pseudomonas* spp.). Weeds were manually removed three times a year  
30 (mid-July, early August and mid-September) from all beds.

### 32 *Season of Cultivation and Selection of Cultivars*

33  
34 In eastern India and Bangladesh, the principal season for cultivation of rice is the monsoon season (June –  
35 October), and most rice farms in the region are rainfed (Pandey and Pal 2007; Government of West  
36 Bengal 2009). Since the introduction of the “green revolution” in the late 1960s, cultivation of semi-dwarf  
37 *boro* (summer) rice with high harvest index has intensified rice production in irrigated farms (Fujita

2010). The semi-dwarf, photoperiod-insensitive high input-responsive “green revolution” varieties are cultivated in both wet and dry seasons (IFPRI 2002; Mishra 2002). Nevertheless, *aman* (winter-harvest) rice, grown in the period June-December, contributes to a major portion of rice production in the region (Government of West Bengal 2009; Fujita 2010). Most traditional *aman* varieties are photoperiod-sensitive tall landraces, cultivated on both lowland (bunded paddy) and upland (rainfed dryland) farms. Our use of the terms ‘upland’ and ‘lowland’, in conformity with the standard description of Asian rice production ecosystems, refer to the poor and high water holding capacity of paddy farms, respectively, and “have no relation to the elevation or topography where the rice is grown” (Linguist et al. 2006: 29).

Basudha farm is a mosaic of rainfed upland and lowland fields. For rainfed upland plots, we chose Tulsa, a short duration (98 days) landrace. Shiuli, a medium duration (130 days) landrace, was selected for rainfed lowland plots. Agronomic and morphological characteristics of both these varieties are described in Deb (2005)<sup>1</sup>. Contingent on the arrival of the monsoon rain, rice seeds were sown in the first week of July in 2005, and a week later in subsequent years. Young seedlings of different ages (6 to 28 days after germination) were transplanted in discrete batches to the experimental plots adjacent to the nursery.

#### *Design of the Study*

Seeds of both varieties were directly sown on puddled seedbeds, and the age of seedlings counted from the day of their germination. Thus, all transplant ages expressed here in number of days (d) denote days after establishment of germinated seedlings in nursery beds. In the first year of the experiment (2005), 3 replicated plots of Shiuli (adapted to rainfed lowland) and 3 replicated plots of Tulsa (adapted to rainfed upland), were randomly selected on Basudha's organic farm. For each cultivar, 3 replications of 8 beds, each bed of 2 m x 2m size, were planted to 6 d-, 8 d-, 10 d-, 12 d-, 14 d-, 16 d-, 18 d-, and 28 d-old seedlings. The rationale for our inclusion of the 28 d transplants is that transplanting of seedlings of  $\geq 28$  days is the long-standing practice throughout eastern India (Pandey and Pal 2007; Fujita 2010). On each plot of our experiment, all seedlings were planted singly, at 25 cm x 25 cm spacing (16 hills/ m<sup>2</sup>). Our experimental design was in full conformity with the SRI protocol as stipulated in Stoop *et al.* (2002) and Uphoff (2003), and included different seedling ages at transplanting for comparison. From each bed, 24 hills (3 random hills from each row) were semi-randomly selected for harvest. All panicles from the

<sup>1</sup> Morphological characteristics relevant to selection of the rice varieties in this study are as follows.

Landrace	Duration (d)	Mean Panicle Density	1000-Grain weight (g)	Grain Shape	Special characteristics
Shiuli	130	233	32.8	Long bold	
Tulsa	98	112	15.9	Short bold	Moderately drought tolerant

Source: Deb (2005)

1 selected hills were examined for enumeration of mean number of grains per panicle (panicle density),  
 2 total grain count per hill (TG), and yield (total grain weight per unit area).

3

4 **Table 1:** Matrix of Difference Between Means of Panicle Density (PD), Grain Output per Hill (TG) and Yield (YD)  
 5 for the Lowland Variety Shiuli (upper diagonal) and the Upland Variety Tulsa (lower diagonal). Letters in italics  
 6 denote significance of difference at  $p < 0.05$ , and in boldface,  $p < 0.01$ . Blank indicates no difference.

7

Transplant Age (d)	6	8	10	12	14	16	18	28
6			<i>PD</i> <i>YD</i>	<i>PD</i> <i>TG</i>	<i>PD</i> <i>TG</i> <b>YD</b>	<i>TG</i> <i>YD</i>	<i>PD</i>	<i>PD</i> <i>TG</i> <b>YD</b>
8					<i>TG</i> <b>YD</b>	<i>TG</i> <i>YD</i>	<b>TG</b> <i>YD</i>	<i>TG</i> <i>YD</i>
10	<b>TG</b> <i>YD</i>	<i>PD</i> <b>YD</b>			<i>PD</i> <b>TG</b>	<i>TG</i> <b>YD</b>	<i>PD</i> <i>TG</i> <i>YD</i>	<i>TG</i> <i>YD</i>
12	<i>PD</i> <i>TG</i> <i>YD</i>	<b>PD</b> <b>TG</b> <i>YD</i>	<i>PD</i>			<i>TG</i> <b>YD</b>	<i>TG</i> <i>YD</i>	<b>TG</b> <b>YD</b>
14	<i>TG</i> <i>YD</i>	<i>PD</i> <b>TG</b> <i>YD</i>	<i>PD</i> <i>TG</i> <b>YD</b>			<i>PD</i>	<i>TG</i> <i>YD</i>	<i>PD</i> <i>TG</i> <b>YD</b>
16	<i>PD</i>	<i>PD</i> <i>TG</i> <b>YD</b>	<i>PD</i> <b>TG</b> <i>YD</i>	<i>TG</i> <b>YD</b>				<i>TG</i> <i>YD</i>
18	<i>TG</i> <b>YD</b>	<i>TG</i>	<i>PD</i> <i>YD</i>	<i>PD</i> <b>YD</b>	<i>TG</i> <i>YD</i>			
28	<b>PD</b> <b>TG</b> <i>YD</i>	<i>PD</i> <i>TG</i>	<i>PD</i> <b>YD</b>	<i>TG</i> <b>YD</b>	<i>PD</i> <b>TG</b> <i>YD</i>	<i>YD</i>		

8

9 The data of the first year (2005) were analyzed to detect the difference between the means of productive  
 10 tillers per hill (PT), number of grains per panicle (or panicle density, PD), total grain counts per hill (TG)  
 11 and yield among different seedling ages for each rice variety. A homogeneity  $\chi^2$  test (= 25.8, df = 23)  
 12 confirmed homogeneity of data from the replicated beds planted to the 8 seedling ages at transplanting  
 13 from both varieties. Results of sequential pairwise  $t$  tests between the means of PD, TG and yield ( $\text{g m}^{-2}$ )  
 14 of all seedling ages at transplanting are given in Table 1, which indicates that

1 (i) there was no significant difference ( $p > 0.1$ ) in PD, nor in TG, when compared between their  
2 means for transplant ages  $\square$  (6 d and 8 d), (10 d and 12 d), (14 d and 16 d), (16 d and 18 d) and (18 d and  
3 28 d) for both varieties.

4 (ii) Significant differences existed between means of TG and Yield for transplant ages  $\square$  (6 d, 8  
5 d, 10 d, 12 d, 14 d) and for the age of 28 d.

6 (iii) The means of PT varied between different seedling ages and between the rice varieties. The  
7 variability of the tiller numbers was too large for any seedling age to discern any definite trend.

8 (iv) The means of grain yield (in weight per unit area) for transplant ages  $\square$  (6 d, 8 d, 10 d, 12 d,  
9 14 d, 16 d), compared to that for 28 d was significantly different for both varieties.

10  
11 Guided by these preliminary findings, 8 d-, 12 d- and 16 d-old transplants were not repeated in the next  
12 phase of our study. In the subsequent 4 crop cycles, from 2006 to 2009, Tulsa and Shiuli rice seedlings  
13 were transplanted separately in four plots (with 3 replications), with each plot assigned to a discrete  
14 seedling age – 6 day-, 10 day-, 14 day- and 28 day-old seedlings for Tulsa, and 10 day-, 14 day-, 18 day-  
15 and 28 day-old seedlings for Shiuli. Following the single seedling transplanting (SST) technique of the  
16 SRI, seedlings of all ages were transplanted with single seedlings per hill. In addition, a plot for multiple-  
17 seedling transplanting (MST) for 28 d-old transplants, with 3 replications, was also maintained for each  
18 variety. The 28-day MST plots, planted with 3-4 seedlings per hill, represent the conventional rice  
19 farming practice of eastern India. Each plot measured 2 m x 2 m, planted to 64 hills in 8 rows and 8  
20 columns at 25 cm x 25 cm spacing. Thus, the planting density was the same ( $16 \text{ hills m}^{-2}$ ) for all seedling  
21 ages, in all years, and for both SST and MST.

22  
23 A structured random sample of 11 hills (comprised by 2 randomly chosen hills from either the first or  
24 second row, and 3 randomly chosen hills from each of 3 alternate rows) were selected and marked, and  
25 the number of productive tillers (PT) of each selected hill counted after flowering. At maturity, all  
26 (primary, secondary and tertiary) panicles from each selected hill were harvested for enumeration of  
27 grains. Thus, the total number of panicles that were sampled and counted over the 4 years of study was:  
28 [2 (cultivars) x {4 (seedling ages SST) + 1 (28 days MST)} x 11 (hills) x  $n$  (panicles/ hill) x 3  
29 (replications) x 4 years] = 1320  $n$ . Mean PD and mean TG were estimated from manual counting of grains  
30 of all sampled panicles from each plot. From each of the 1320 hills, a sample of 100 grains was weighed  
31 on a digital balance, and the mean 100-grain weight (MGW) was determined for each treatment from  
32 100-grain weights from 3 replicate plots. Yield from each plot was calculated as the product of hill  
33 density ( $\text{No. m}^{-2}$ ), mean TG ( $\text{No. hill}^{-1}$ ), and MGW (g):

34  
35 
$$\text{Yield (g m}^{-2}\text{)} = (16 \times \text{TG} \times \text{MGW}) / 100.$$
  
36

37 All sampled panicles are preserved in our laboratory for re-examination/verification by SRI researchers.

1 *Statistical Analyses*

2

3 Statistical comparisons between treatment beds (among all seedling ages) were based on the PT, TG and  
4 PD and yield data, obtained from 3 spatial replicates of each experimental treatment in respect of rice  
5 variety and seedling age.

6

7 After 2005, all experimental treatments, farm plot locations and the farm conditions were identical in the  
8 subsequent 4 years (from 2006 to 2009). The experiments over the 4 years may therefore be considered as  
9 4 temporal replications of the experiment. These experiments were repeated each year afresh with the  
10 same design and protocol, with replicated plots, so each experimental unit sampled independently in  
11 successive years constitutes a genuine temporal replication, not pseudoreplication (Hargrove and  
12 Pickering 1992; Underwood 1997). Accordingly, all PT, PD, TG and yield data from spatial replicates,  
13 collected over 4 years were aggregated, and subjected to a Student-Newmann-Keuls test for normality of  
14 distribution. The aggregate data showed that their distribution was not normal, and therefore Student's *t*-  
15 test was obviated. Instead, a Mann Whitney *U* test was performed, with 95% confidence limit. All PT,  
16 TG, PD and yield data for each treatment shown here are the mean values over all spatial and temporal  
17 replicates over 4 years.

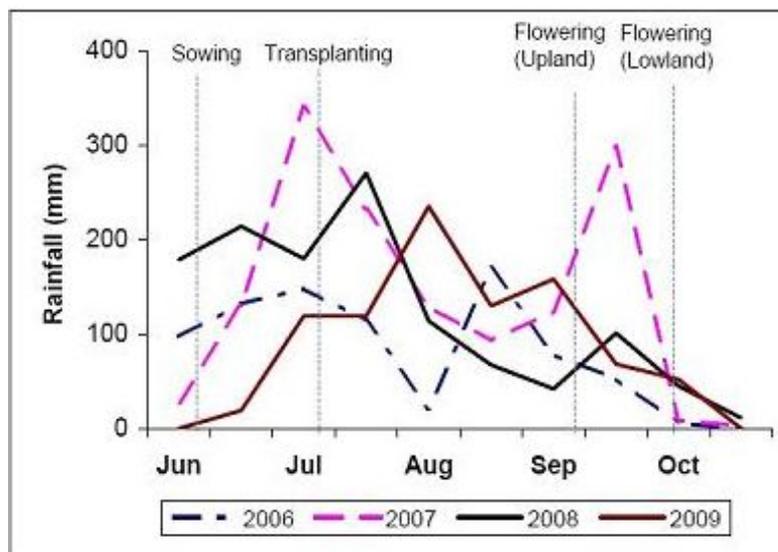
18

19 **Results**

20

21 A summary of the mean number of panicles per hill (or productive tiller number, PT), panicle density  
22 (PD), total grain output per hill (TG) and grain yield ( $\text{g m}^{-2}$ ) from all replications for each year are given  
23 in Table 2, and discussed under separate rubrics.

24



25

26

27

**Fig. 1:** Variation over the period from 2006 to 2009 in the amount of precipitation on Basudha farm.

Overall, the PD, TG, and yield figures are considerably less for the short-duration upland rice variety Tulsa than for the medium-duration lowland variety Shiuli. However, the mean PT for young seedlings was consistently lower for all SST treatments of all seedling ages than for the conventional 28 day MST (henceforth shorthanded as “the MST”). The yearly fluctuations in PD, TG and yield in both rice cultivars seem to be influenced by variations in monsoon precipitation (Fig. 1), but examination of this relationship is beyond the scope of this study.

**Table 2:** Year-wise Comparison of Total Grain Output per Hill (TG), Panicle Density (PD), Productive Tillers (PT) and Grain Yield ( $\text{g/m}^2$ ) (YD) for Different Seedling Ages at Transplanting. SAT = Seedling age (days) at transplanting. Values are rounded up for brevity.

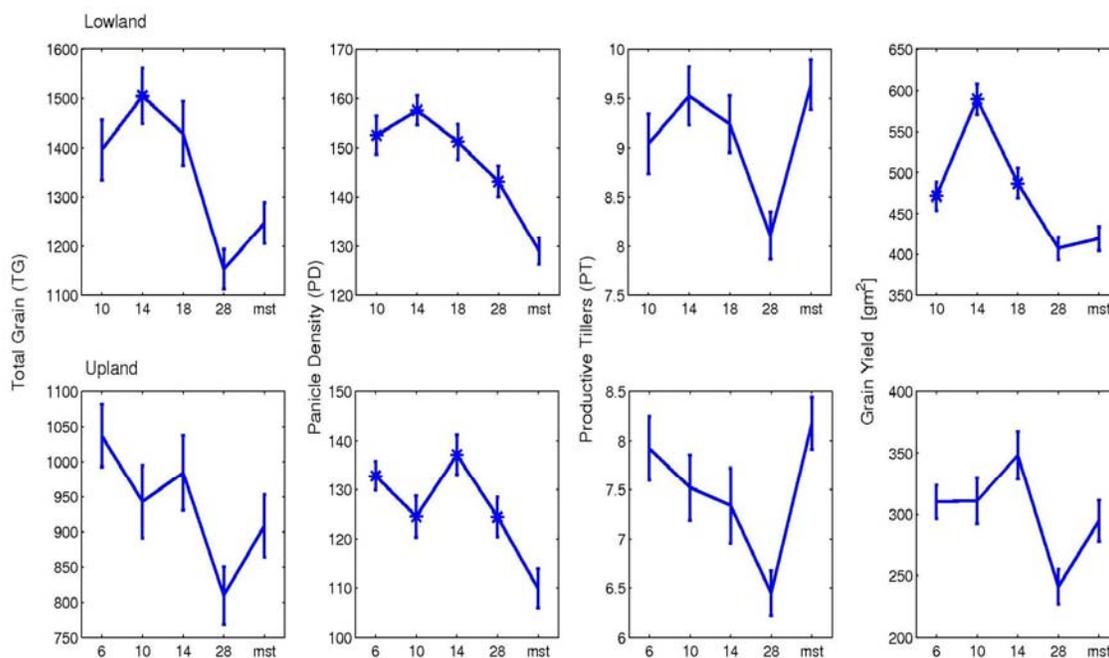
SAT	2006				2007				2008				2009			
	TG	PD	PT	YD												
<b>Rice Variety: SHIULI</b>																
10 SST	2119	191	11	555	1281	141	9	493	972	115	8	422	1139	157	7	402
14 SST	2214	190	12	637	948	95	10	720	1164	129	9	514	1122	164	7	481
18 SST	2214	197	11	612	1300	143	9	518	1001	134	8	362	1118	144	8	410
28 SST	1856	191	10	434	1201	134	9	435	890	111	8	357	1123	145	8	408
28 MST	1561	149	11	423	1217	127	10	440	964	119	8	363	1324	128	10	453

**Rice variety: TULSA**

6 SST	601	102	6	189	1372	137	10	384	760	104	8	217	1339	179	8	570
10 SST	747	119	6	241	1485	134	11	446	756	127	6	255	1208	183	7	566
14 SST	1013	128	8	292	1263	138	9	354	849	121	7	251	1108	157	7	373
28 SST	504	77	6	179	793	133	6	239	655	115	6	174	1224	157	8	395
28 MST	1038	112	9	273	932	101	9	291	533	80	7	171	1326	158	9	483

Yield Characteristics in the Rainfed Upland Variety Tulsa:

1. The mean panicle density (PD) of SST 28 d transplants was significantly greater than that of the MST transplants (Table 3).
2. There was no difference in TG between transplants of age 6 days and 28 days, but the TG for 10 d and 14 d transplants were significantly greater than 28 d transplants (Table 4).
3. None of the SST plots were any different from the MST plots in TG counts (Tables 3 and 5).



**Fig. 2:** Total grain count per hill (TG), panicle density (PD), productive tillers (PT) and grain yield for traditional rice varieties adapted to rainfed lowland (top) and upland (bottom) farms. Abscissae show seedling ages (in days). MST denotes multiple transplants of 28-day old seedlings. Vertical bars represent standard errors. Values marked with an asterisk are significantly ( $p < 0.05$ ) different from that of MST.

4. There was no difference in PT between 6 d and 10 d transplants, but PT of 14 d transplants were significantly more numerous than that of 28 d transplants (Table 4). However, the MST produced significantly more PT than 6 d, 10 d (Table 5), and 28 d transplants (Table 3).

5. Grain yield ( $\text{g m}^{-2}$ ) for 6 d, 10 d and 14 d transplants were significantly higher than 28 d transplants (Table 4), but the yields from these SST plots were statistically no different from the conventional MST (Table 5). The yield of 28 d SST was significantly less than that of the MST (Table 3).

**Table 3:** The effect of transplanting method (SST vs MST) with 28 day-Old Rice Plants on Productive Tillers per Hill (PT), Grain Output per Hill (TG), Panicle Density (PD), and Grain Yield ( $\text{g m}^{-2}$ ).

	Upland Rice (Tulsa)	$p$	Lowland Rice (Shiuli)	$P$
PT	28 d MST > 28 d SST	0.000	28 d MST > 28 d SST	0.000
TG	28 d SST $\approx$ 28 d MST	0.170	28 d SST $\approx$ 28 d MST	0.063
PD	28 d SST > 28 d MST	0.000	28 d SST > 28 d MST	0.001
Yield	28 d MST > 28 d SST	0.03	28 d SST $\approx$ 28 d MST	0.511

**Table 4:** Comparison of Effects of Seedling Age on Productive Tillers per Hill (PT), Grain Output per Hill (TG), Panicle Density (PD), and Grain Yield ( $\text{g m}^{-2}$ ) for all SST treatments. Relationships that are statistically not significant ( $p > 0.05$ ) are not shown.

	<b>Upland Rice (Tulsa)</b>	<i>P</i>	<b>Lowland Rice (Shiuli)</b>	<i>p</i>
PT	14 d > 28 d	0.003	10 d > 28 d	0.009
			14 d > 28 d	0.000
			18 d > 28 d	0.011
TG	10 d > 28 d	0.039	10 d > 28 d	0.011
	14 d > 28 d	0.001	14 d > 28 d	0.000
			18 d > 28 d	0.008
PD	10 d > 28 d	0.093	14 d > 28 d	0.040
			14 d > 18 d	0.041
			10 d > 28 d	0.011
Yield	6 d > 28 d	0.04	14 d > 28 d	0.000
	10 d > 28 d	0.000	18 d > 28 d	0.008
	14 d > 28 d	0.000	14 d > 10 d	0.000
			14 d > 18 d	0.000
			14 d > 18 d	0.000

**Table 5:** The effect of seedling age with SST on Productive Tillers per Hill (PT), Grain Output per Hill (TG), Panicle Density (PD), and Grain Yield ( $\text{g m}^{-2}$ ), Compared to Conventional MST of 28 day-Old Seedlings. Relationships that are statistically not significant are not shown.

	<b>Upland Rice (Tulsa)</b>	<i>P</i>	<b>Lowland Rice (Shiuli)</b>	<i>p</i>
PT	6 d < 28 d MST	0.045	18 d < 28 d MST	0.038
	10 d < 28 d MST	0.001		
TG			14 d > 28 d MST	0.01
PD	6 d > 28 d MST	0.011	10 d > 28 d MST	0.000
	10 d > 28 d MST	0.000	14 d > 28 d MST	0.000
	14 d > 28 d MST	0.000	18 d > 28 d MST	0.000
Yield			10 d > 28 d MST	0.05
			14 d > 28 d MST	0.000
			18 d > 28 d MST	0.021

#### Yield Characteristics in Lowland Variety Shiuli

1. PD from 28 d SST was significantly greater than that from the MST plots (Table 3). However, TG and yield of the MST was no different from 28 d SST (Table 3), indicating that the absolute number of grains per hill for older (>20 days) seedlings is unlikely to be influenced by the method of transplanting (SST or MST).

- 1 2. PD does not show any significant difference between 10 d and 14 d plots, but is significantly greater  
 2 for 14 d than for 18 d and 28 d transplants (Table 4).  
 3 3. PT was significantly less for 28 d transplants than for all younger transplants (Table 4), and also less  
 4 than the MST (Table 3).  
 5  
 6 4. TG showed no significant difference amongst 10 d, 14 d and 18 d transplants, all of which were  
 7 significantly greater than TG for 28 d (Table 3). TG for 14 d transplants was significantly different from  
 8 the MST (Table 5).  
 9  
 10 5. Plots with 10 d, 14 d and 18 d transplants produced significantly more PT, TG and yield than SST 28 d  
 11 transplants (Table 4).  
 12  
 13 6. Grain yield for 14 d transplants was greater than 10 d, 18 d and 28 d transplants (Tables 4 and 5).  
 14

15 **Table 6:** Regression of Grain Output per Hill (TG) on Productive Tillers (PT).  
 16

Seedling Age (days) at Transplanting	Slope	Constant	<i>r</i>	<i>t</i>
<i>Lowland Variety Shiuli</i>				
10	161.80	67.35	0.81	5.10*
14	154.56	62.48	0.86	6.20*
18	189.79	325.24	0.84	5.74*
28	128.24	112.80	0.78	4.61*
28 MST	130.77	13.15	0.79	4.82*
All Treatments	159.64	104.01	0.81	5.10*
<i>Upland Variety Tulsa</i>				
6	120.57	99.30	0.87	6.48*
10	119.02	94.02	0.87	6.48*
14	119.63	43.20	0.77	4.48*
28	139.43	89.62	0.78	4.67*
28 MST	120.24	74.63	0.71	3.74*
All Treatments	120.34	40.80	0.81	5.10*

17  
 18  
 19 The only yield component that was significantly better in the conventional (28 d MST) plots than in SST  
 20 plots with both young and old transplants of the upland variety Tulsa, is the mean number of productive  
 21 tillers per hill (Tables 3 and 5). MST 28 d transplants produced significantly more tillers than 18 d-old  
 22 Shiuli transplants (Table 5). In contrast, SRI plots with young transplants of Shiuli produced significantly  
 23 more tillers than SST 28 d plots (Table 4). A strong positive relationship holds between productive tillers

1 and grain number per hill across all seedling ages and within the two 28 d groups (SST and MST). The  
2 effect seems to be consistent in both the cultivars under study (Table 6).

### 3 4 **Discussion**

5  
6 This study examines, for the first time, the effect of SRI practice on yield characteristics of two traditional  
7 photoperiod-sensitive landraces, repeated over 4 seasons. We examine here the standard SRI claims of  
8 increased number of productive tillers per hill (PT) and grain yields, under separate rubrics. We then  
9 critically discuss the effects of various components of the SRI methodology – (a) single transplanting of  
10 (b) young seedlings, and posit our study in the light of previous experimental findings.

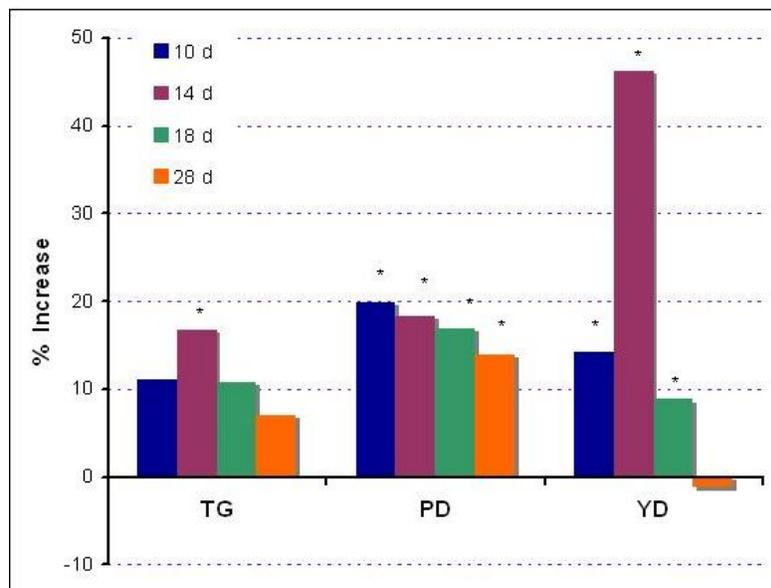
#### 11 12 *Productive Tiller Numbers*

13 The panicle density (PD), conjointly with the number of productive tillers (PT) determines the absolute  
14 grain yield on any farm. Thus, high yields are associated with large numbers of spikelets per unit area (De  
15 Datta 1981), which rice scientists and farmers seek to achieve by using high plant densities (directly  
16 seeded or transplanted in clumps). However, stresses occurring during the later growth stages cause 20%  
17 to 50% tiller mortality, and unfilled spikelets, which normally are about 15% at harvest (Kropff *et al.*  
18 1994). The SRI practices may preclude such stresses by early transplanting of seedlings before the onset  
19 of the tillering process (Stoop *et al.* 2002), leading to a positive correlation between PT and TG. In our  
20 study, the correlation of TG with PT is uniformly strong in all treatments with young seedlings as well as  
21 with conventional transplantation of 28 d-old seedlings (Table 6), indicating that PT does not significantly  
22 depend on seedling age at transplanting.

23  
24 Profuse tillering ( $>50 \text{ hill}^{-1}$ ) is often reported from SRI farms (de Laulanie 1993; Stoop *et al.* 2002;  
25 Uphoff 2003). Profuse tillering may be detrimental to grain production, if the proportion of non-  
26 productive tillers is also high. A greater proportion of non-productive tillers may result in grain yield  
27 reduction, owing to high respiration cost and dry matter loss (Schnier *et al.* 1990; Horie *et al.* 2005).  
28 However, SRI seems to reverse this relationship, and most SRI studies report greater frequency of PT  
29 associated with greater grain yield. Stoop *et al.* (2002) report that with 25 cm x 25 cm or wider spacing of  
30 transplants, “farmers in Madagascar using SRI methods most skilfully can produce plants with more than  
31 100 fertile tillers; the highest number reported is 140.” More modest means of 17.9 and 18.8 per hill  
32 respectively were reported by Thakur *et al.* (2009) and Thakur *et al.* (2010) at 25 cm x 25 cm spacing on  
33 their modified SRI plots. At the same spacing, rice plants on our SRI plots generated an overall mean of  
34 9.7 PT per hill for Shiuli, and 7.7 PT per hill for Tulsa, both in rainfed condition. The highest mean PT  
35 was 10.9 for Shiuli in 2006, and 9.1 for Tulsa in 2007.

36  
37 Our data thus do not conform to the standard report (de Laulanie 1993; Gani *et al.* 2002; Uphoff 2003;

1 Thakur *et al.* 2009, 2010) of an enhanced tillering effect in SRI. On the contrary, PT is significantly  
 2 greater on the MST plots than the SRI plots planted with 6 d- and 10 d-old seedlings of Tulsa, and 18 d-  
 3 old seedlings of Shiuli (Table 5 and Fig. 2), indicating that SRI does not seem to have any favorable  
 4 effect on PT, for at least the rice varieties under study. The reason for this nonconformity to the  
 5 previously reported SRI results is that the landraces, Shiuli and Tulsa, used in our study were not  
 6 traditionally selected or bred for high tillering ability. As the tillering ability differs between rice varieties,  
 7 “those varieties which have high tillering ability perform better as compared to the shy tillering ones”  
 8 under SRI method (Mahender Kumar *et al.* 2010: 64). The SRI method would not significantly enhance  
 9 the tillering ability of Shiuli, Tulsa, and many other inbred varieties that are not selected for this  
 10 characteristic. Rather, SST would tend to reduce the number of PT per hill in the landraces examined.  
 11



12  
 13 **Fig. 3:** The effect of single-seedling transplanting of the lowland variety Shiuli with different transplant  
 14 ages on grain numbers per hill (TG), panicle density (PD), and grain yield (YD), compared to multiple-  
 15 seedling transplantation of 28 d-old seedlings. Each column shows the median value for a transplant age.  
 16 An asterisk indicates significant ( $p < 0.05$ ) difference from the MST.  
 17  
 18

19 *Grain Yield*

20 Our study seems to corroborate the standard claim of significant yield increase with early transplantation  
 21 (Stoop *et al.* 2002; Uphoff 2003; Pasuquin *et al.* 2008; Uphoff *et al.* 2008), but does not corroborate any  
 22 miraculous yield improvement. As Fig. 3 shows, transplanting of 10 d-, 14 d- and 18 d-old seedlings of  
 23 the lowland variety Shiuli had a significantly positive effect on both PD and yield compared to  
 24 conventional MST 28 d transplants. However, the effect disappeared in the upland variety Tulsa, whose  
 25 younger transplants showed no difference from the MST in both TG and yield (Table 5 and Fig. 2).  
 26

1 The standard recommendation in SRI literature (e.g. de Laulaine 1993; Stoop *et al.* 2002; Uphoff 2003) is  
2 to transplant seedlings between 8 d and 16 d, implying absence, or uncertainty of the effect of transplants  
3 younger than 8 d. However, Gani *et al.* (2002) and Pasuquin *et al.* (2008) found that 7 d-old transplants  
4 also produced early tillering and higher yield than 21 day-old transplants. Our study shows that for the  
5 upland variety Tulsa, grain yields of younger transplants of ages between 6 d and 14 d are no better than  
6 that of the MST, while young transplants of Shiuli yield better than both MST and SST 28 d-old  
7 transplants (Tables 4 and 5). It seems likely that the extent of the effect of seedling age at transplanting on  
8 yield differs with varietal genotypes (Pasuquin *et al.* 2008), which might explain the variability of effects  
9 of transplant age of < 8 d

### 11 *The Effect of SST on Yield Components*

12 Transplantation of single seedlings with wide spacing is an essential component in SRI, and is thought to  
13 be a significant determining factor for tillering and grain yield improvement, even for conventional  
14 seedling age of >26 d (San-Oh *et al.* 2004; Horie *et al.* 2005). Our study, however, shows that with 28 d-  
15 old seedlings, SST seems to be of no advantage over MST in terms of PT, TG, PD and yield for the  
16 upland variety Tulsa (Fig. 2). Rather, the yield of MST was greater than SST for 28 d transplants of Tulsa  
17 (Table 3). Furthermore, PT of MST plots was significantly greater than that of most SST plots, for both  
18 varieties in this study (Tables 3 and 5). However, PD and yield of the lowland variety Shiuli was  
19 significantly greater for all young transplants under SRI than that of the MST (Fig. 3).

21 In this study, all SRI plots with SST produced significantly greater PD than the MST plots, for both  
22 upland and lowland varieties (Tables 3 and 5). Conversely, SST plots with 28-day old seedlings produced  
23 significantly less PT than MST plots (Table 3), indicating that SST may suppress tillering, possibly  
24 resulting in a yield drag, in old transplants. Furthermore, 28 d SST and MST plots showed no difference  
25 in TG counts for both rice varieties (Table 3). This finding is consonant with the findings of Oziegbe and  
26 Faluyi (2007) with 21-day old seedlings, and of Miah *et al.* (2004), with 26-day old seedlings, planted at  
27 the same spacing. Moreover, yield decline was also reported for SST of 26 d-old (Prasad and Sheer 1992)  
28 and 30 d-old (Rahman *et al.* 2007) seedlings of different rice cultivars, in spite of adequate N availability  
29 in soil.

### 31 *The Effect of Early Transplantation*

32 Some early experiments in Japan recorded a positive effect of early ( $\geq 10$  d) transplanting on grain yield,  
33 although these studies did not consider other components of SRI (Horie *et al.* 2005). Our results (Table 4  
34 and 5) show that the early age of seedlings at transplantation seems to be consistently conducive to grain  
35 yield enhancement.

37 However, when the TG and PD data are examined separately for years, the effect of early age of seedlings

1 is not prominent, especially in the years of late monsoon arrival (2006 and 2009). For photoperiod-  
2 sensitive rice varieties, the younger the seedlings at transplanting, the longer the time to heading and  
3 maturity. Therefore, in places where growth duration is affected by temperature, and/or availability of  
4 water, “young seedlings do not have enough time to express their potential” (Horie *et al.* 2005: 267).  
5 Nevertheless, Tables 4 and 5 show a consistent advantage of early transplanting in TG and grain yield  
6 over 28 d-old transplants on SST plots. In contrast, conventional transplantation of multiple old seedlings  
7 tends to engender significantly more PT than SRI transplants, especially the 6- and 10-day old transplants  
8 of Tulsa (Table 5). For Shiuli, none of the SST plots produced more productive tillers than the MST  
9 (Table 3 and 5), but within SRI plots, the mean PT of younger transplants was significantly greater than  
10 28 d-old transplants (Table 4).

### 11 *The Role of Water Management*

12 Scanty rainfall in low-rainfall districts and the late arrival of the monsoon rain constitute water stress for  
13 the rice plant, affecting its yield characteristics (Sarvestani *et al.* 2008). It is plausible that fluctuations in  
14 rainwater availability around vegetative and panicle initiation stages of the rice plants (Fig. 1) might have  
15 influenced the observed variability of grain outputs on both SRI and the MST plots in our study.  
16 However, our study was not designed to ascertain the effect of water availability on SRI, nor would the  
17 comparable datasets for only 4 years of our study period allow us to infer any relationship.

### 19 *The Role of Soil Nutrients*

20 Soil nutrient level is an important factor for high yielding response of rice (Rahman *et al.* 2007).  
21 Proponents of SRI have attributed the reported yield increment from SRI to a greater number of PT, and  
22 more efficient resource capture and apportionment of nutrients for grain production (Stoop *et al.*, 2002;  
23 Nissanka and Bandara 2004). Successful yield enhancement under SRI is reported only from farm plots  
24 with high N-supplying ability of the soil and accumulated organic C from surface to deep soil, attributable  
25 to the long-term practices of extensive organic applications and deep plowing; so the high yield from  
26 these SRI farms was mainly due to high soil fertility, especially “the great nitrogen-supplying ability of  
27 the soil, rather than ‘synergetic effects’ [*sic*] of SRI components” (Tsujimoto *et al.* 2009: 70). The low N  
28 and K levels in the soil of Basudha farm thus may account in this study for overall low grain yields.

### 31 *The Role of Transplant Density and Spacing*

32 Spacing of rice hills at 25 cm x 25 cm (up to 16 transplants m<sup>-2</sup>) is considered to be most conducive for a  
33 combination of yield characteristics in the SRI (Stoop *et al.* 2002; Thakur *et al.* 2010), and we have  
34 strictly followed this stipulated spacing on all SRI and conventional plots. Our experiments therefore  
35 cannot tell if the results are likely to change with closer spacings or greater transplant densities. Some  
36 experiments (Sheehy *et al.* 2004; Latif *et al.* 2005; Menete *et al.* 2008), however, found the use of wider  
37 spacing of rice plants in the SRI to have resulted in lesser yield per unit area than conventional rice

1 farming practices. In these studies, SRI failed to achieve the desired yield enhancement plausibly because  
2 the growth of seedlings transplanted at wide spacing “exceeded the [nutrient] capacity of those soils”  
3 (Thakur *et al.* 2010: 156).

#### 4 5 *The Role of Genotypes*

6 Yield enhancement was observed in certain studies, even where SRI was not strictly followed  
7 (Senthilkumar *et al.* 2008; Thakur *et al.* 2010). Conversely, SRI failed to elicit yield improvement in  
8 some studies (McDonald *et al.* 2006, 2008). Both types of evidence indicate that rice yield components  
9 are flexible, responding to different field management regimes depending on the cultivar genotype. Some  
10 cultivars may not be suitable for SRI conditions (e.g. low transplant densities, limited water supply).

11  
12 Most rice breeding programs employ selection criteria with respect to tillering (only three to four  
13 tillers/plant), optimum plant densities and response to chemical fertilizers, all of which differ  
14 fundamentally from what would be desirable for SRI-adapted cultivars (Stoop *et al.* 2002). All the yield  
15 components – tillering ability, panicle density and grain weight – depend on the cultivar genotype, albeit  
16 greatly influenced by environmental conditions and field management practices (De Datta 1981).  
17 Extensive interactions between genotypes and environment result in adaptation of different varieties to  
18 specific environmental conditions (Xing and Zhang 2010). For a reliable prediction of the yield response  
19 to SRI, it is necessary to identify the “cultivars that have been proven to be optimally adapted to a  
20 particular system” (Stoop *et al.* 2009). The cultivars used in our study were shy tillering landraces, and  
21 therefore showed no definitive change in PT in the SRI conditions. However, the grain yield components  
22 of the lowland variety Shiuli under SRI conditions showed significant improvements compared to the  
23 MST treatment, indicating its responsiveness to SST and younger seedling age at transplanting.

#### 24 25 26 **Limitations of the study and the need for further research**

27  
28 Most of the studies that have reported spectacular effects of SRI used only a few rice varieties, most of  
29 which are modern cultivars, grown in irrigated lowland conditions. Consequently, their practical  
30 agronomic relevance to rainfed local rice varieties in much of South Asia remains limited. Also, the  
31 evidence in literature of adverse or no effect of SRI is based on short-term, simple assessments through  
32 field experiments conducted in a single season (e.g. Sheehy *et al.* 2004) or confined to a single rice  
33 genotype (e.g. Senthilkumar *et al.* 2008; Latif *et al.* 2009).

34  
35 We have not used any modern rice varieties in our study, because they are usually bred to optimize  
36 production under favorable soil and water conditions (Pandey and Pal 2007; Stoop *et al.* 2009). Instead,  
37 we have used two traditional rice landraces, which are tolerant of various local environmental stresses  
38 (such as low soil fertility). However, not all traditional varieties can outperform modern varieties in

1 marginal environments. The yield performance of the traditional variety Basmati, for example, is  
2 marginally better under SRI than under conventional transplanting practice, but its grain yield is  
3 considerably poorer than most hybrid rice varieties under the same management regime (Mahender  
4 Kumar *et al.* 2010). Thus, a comparison of yield performances between modern elite varieties and local  
5 landraces under SRI conditions would be spurious. Our study has precluded this bias, and compared two  
6 low-yield traditional rice varieties that are grown on rainfed upland and lowland farms.

7  
8 Clearly, two local varieties are not adequate to find the degree of genotypic sensitivity of rice varieties to  
9 SRI conditions. However, experimental studies with local landraces are hard to come by. In view of the  
10 wide genetic diversity of rice, with thousands of extant varieties, each adapted to a specific edapho-  
11 climatic condition (Deb 2005; FAO 2009), it may take an indefinite period of time for researchers to  
12 ascertain the precise relationship between the genotypes, grown in different environmental conditions,  
13 and respective grain yield-related characteristics.

## 14 15 16 **Conclusions**

17  
18 Rice grain yield is a quantitative trait and characterized by low heritability and a high genotype x  
19 environment (GxE) interaction (Farooq *et al.* 2009). To determine the effect of a cultivation technique on  
20 yield, it is important to consider the cultivar genotype adapted to specific land type, and local  
21 environmental conditions, including soil nutrient levels and seasons of cultivation (*e.g.* winter vs  
22 summer). Therefore, the complex task of assessing the specific merits of the various rice cultivars and  
23 production systems is “compounded further by the numerous location-specific natural and socio-  
24 economic factors that are encountered in any farming environment” (Stoop *et al.* 2009: 1499).

25  
26 Our study contradicts the inference of McDonald *et al.* (2008) that there is no *prima facie* evidence of  
27 significant yield increase from SRI in wet paddy cultivation in “countries outside Madagascar”, as the  
28 mean yield from young transplants of Shiuli was significantly greater than conventional MST (Fig. 3).  
29 However, the effect is evident only for the lowland variety Shiuli (Table 5 and Fig. 2). For both rice  
30 varieties tested in our experiment, the TG and PD fluctuated with years, in likely response to the amount  
31 of rainfall, but the mean PD in both varieties were greater in young transplants. This is in agreement with  
32 the SRI results from Mali: although experimental land was not optimally levelled and the irrigation  
33 schedule was the same as for the non-SRI irrigation scheme, yield components significantly improved in  
34 SRI plots (Africare 2008; Styger *et al.* 2011). Nevertheless, the extent of yield improvement in our study  
35 is far from spectacular (Fig. 3). It remains to be examined if the yield-enhancing effect of SRI in  
36 Madagascar, Mali and in our study (with Shiuli) is a result of the selection of appropriate rice cultivars,  
37 which have not been used in other experiments in other countries. Because many farmer landraces are

1 characterized by different farmer-selected properties not related to yield components, it seems plausible  
2 that the yield of those rice genotypes (e.g. Tulsa) may not respond well to the SRI conditions, while  
3 others would.

4  
5 The results of our study show that the SRI tends to improve TG for Tulsa with transplant age of 10 and 14  
6 days, and for Shiuli with transplant age of 10, 14 and 18 days, compared to SST plots with 28 d-old  
7 transplants (Table 4). For Shiuli, the only seedling age at transplanting that was associated with  
8 considerable TG enhancement was 14 d, compared to MST (Table 5 and Fig. 3). Yield was also  
9 significantly greater in young Shiuli transplants than the MST (Table 5 and Fig. 3). This apparent yield  
10 advantage of the SRI over conventional MST disappeared in the upland rice Tulsa. Conversely, the SRI  
11 was clearly a disadvantage for PT, compared to the conventional MST (Table 5 and Fig. 2), indicating  
12 that the SRI may not be particularly economical for rain-fed upland varieties, in spite of the fact that  
13 many upland varieties, including Tulsa, are moderately drought tolerant.

14  
15 The controlled water regime of alternate drying and flooding of the SRI may not always improve yield in  
16 lowland varieties, as indicated by Satyanaraya *et al.* (2007). In our study, rice yield improvement in SRI  
17 plots was absent in the upland variety Tulsa. Although the yield from SRI was significantly greater  
18 compared to the conventional MST plots in the lowland variety Shiuli, the extent of improvement was  
19 restrained by water stress from scanty or delayed rains in some years. Given the fact that resource-poor  
20 farmers do not have access to irrigation in their upland farms and must rely on precipitation, SRI may not  
21 be of any practical benefit to rainfed upland farms – unless the production system be coupled with some  
22 reliable water management system, such as stored rainwater for intermittent irrigation during periods of  
23 dry spells. It would therefore be safe to recommend SRI specifically for certain lowland rice varieties,  
24 rather than a blanket prescription for any and all varieties.

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