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# INFLUENCE OF SYSTEM OF RICE INTENSIFICATION (SRI) PRACTICES ON GRAIN YIELD AND ASSOCIATED PHYSIOLOGICAL CHANGES IN RICE PLANTS COMPARED TO CONVENTIONAL FLOODED RICE

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System of Rice Intensification (SRI) management practices depart from conventionally-recommended methods for rice cultivation, aiming to provide rice plants with optimal growing conditions, to enhance yield and resource productivity (Stoop et al. 2002). The benefits of SRI practices have been seen already in 42 countries and are reported to increase yields of irrigated rice by 25–50% or even more (Ceesay et al. 2006; Chapagain and Yamaji 2010; Kabir and Uphoff 2007; Namara et al. 2008; Sato and Uphoff 2007; Satyanarayana et al. 2007; Sinha and Talati 2007; Thakur et al. 2010b; Tsujimoto et al. 2009; Zhao et al. 2010). However, little is known about how SRI practices affect rice plants' morphology, their physiology, and their implications on crop performance. This investigation undertook to assess, through standard agronomic methods, what if any phenotypical changes would be induced by changes in management practices.

The experiments were conducted at the Deras Research Farm, Khurda district, Orissa, India during the 2007 and 2008 dry season (January-May). The soil at the experimental site was classified as *Aeric Haplaquepts*, sandy clay-loam in texture (63% sand, 16% silt, and 21% clay), with pH of 5.5. The experimental design employed randomized complete block design with five replicates and plot sizes of 20×10 $m^2$.

Rice (cv. Surendra) was grown under either of the alternative crop management systems assessed: the System of Rice Intensification (SRI), or traditional flooding (TF) with standard government-recommended management practices. On all trial plots, organic manure (cow dung mixed with straw) @ 5 t $ha^{-1}$ was applied along with chemical fertilizers (N:P:K::80:40:40), so nutrient application was not an experimental variable.

In SRI plots, 12-day-old single seedlings were transplanted at 20×20 cm spacing within 30 min after removal from the nursery; and for TF plots, three 25-day-old seedlings $hill^{-1}$ spaced 20×10 cm. SRI plots were weeded by conoweeder @ 10, 20 and 30 days after transplanting, while TF plots had three hand-weedings at the same intervals. TF plots were kept continuously flooded, and water depth was maintained @ 5-8 cm during the entire vegetative stage. In SRI plots, irrigation water was applied 3 days after the disappearance of ponded water during vegetative stage. After panicle initiation, both SRI and TF plots were kept flooded with a thin layer of water (1–2 cm) and were drained 15 days before harvest.

Three hills with a typical number of panicles were randomly selected from each replicate at the early-ripening stage for measuring xylem exudation rate and root growth. At the flowering stage, number of leaves hill$^{-1}$, their average length and width, leaf angle, leaf area index (LAI); specific leaf weight (SLW) and canopy angle were measured from each replicate. Light interception by the canopy and crop growth rate (CGR) were measured during vegetative stage. From each plot, flag leaf and fourth leaf (from top) were sampled to measure - at flowering, middle-ripening, and late-ripening stages - chlorophyll content, chlorophyll fluorescence (Fv/Fm and ΦPS II), and photosynthesis rate.

To determine yield per unit area, all plants in an area of 3×3 m from each plot were harvested (excluding border rows), with reported grain yield adjusted to 14.5% seed moisture content. All data were statistically analyzed using analysis of variance (ANOVA) technique as applicable to RBD (Gomez and Gomez 1984). The significance of treatment effects was determined using F-test, and least significant difference (LSD) was estimated at the 5% probability level.

Root growth, measured at early ripening stage when active grain-filling starts, was significantly greater in SRI than TF crop. Roots per hill were nearly twice as heavy and were considerably deeper, more than double the length and volume in SRI compared to TF. Root dry weight was not significantly different on a per unit area basis, mainly because of the greater number of hills in TF plots. However, root length density was significantly greater in SRI than TF.

The amount of xylem exudates transported from roots toward the shoot was significantly more in SRI plants at the early ripening stage, both per hill and per unit area. Rate of transport of exudates was also significantly faster, 3 times more in SRI hills than in TF hills or land area.

At flowering stage, the number of leaves per hill and per unit area with SRI was significantly higher; SRI hills had more than twice the number of leaves compared to TF hills. Also, SRI leaves were significantly longer as well as wider than TF leaves. The greater number of larger leaves in SRI crops resulted in significantly higher LAI compared to TF crops. Further, the leaves of SRI plants had higher SLW, indicating thicker leaves than TF plants.

Of particular interest was the difference in canopy structure when evaluated at the flowering stage. SRI hills had a significantly greater canopy angle than TF hills, giving SRI hills a more open structure, with more and better exposure to sunlight. This could be attributed to shallower planting (1-2 cm) under SRI as well as less crowding of SRI plants. At the same time, we found that the angles between the leaf blade and the stem/tiller, flag leaf and panicle axis were less in SRI than TF plants, meaning that SRI leaves are more erect.

During their initial growth stages (up to 40 DAG) TF canopies intercepted more solar radiation than did SRI canopies. At 50 DAG, there were no significant differences in light interception. Then beyond 50 DAG, light interception in SRI plots was significantly more than in the TF plots. At panicle initiation, light interception reached 89% in SRI plots, while it was only 78% in TF canopies, this giving SRI plants a 15% advantage.

Crop growth rate was higher in TF crops up to 60 days after germination, however, beyond 60 DAG, CGR with TF declined compared to that observed with SRI. SRI CGR showed a continuously increasing trend throughout the vegetative stage as a result of unimpeded tillering.

Leaf chlorophyll content, maximum quantum efficiency (Fv/Fm), actual quantum efficiency (Φ PS II), and photosynthetic rate were all significantly greater in plants grown under SRI practice compared to TF plants during reproductive and ripening stages. As plant development progressed, these parameters decreased under both cultivation practices. However, in SRI leaves, the decreases were slower than in TF leaves, and levels remained higher.

SRI hills had nearly double the number of tillers/panicles than TF hills. There was no significant difference in tillers per unit area; however, number of panicles per unit area was significantly higher under SRI. Further, average SRI panicle length was higher than for TF panicles, carrying nearly 40% more grains. Percentage of ripe-grains and 1000-grain weight were also significantly higher in SRI plants than TF plants.

The significant improvement in yield components resulted in 42% higher grain yield under SRI management than from crop grown under TF (6.4 t/ha vs. 4.5 t/ha). Straw weight per unit area was, on the other hand, greater in TF, resulting in a significant decrease in Harvest Index as compared with SRI plots.

Practices associated with SRI management have been shown to be advantageous in others' experiments with irrigated rice, such as: use of single seedlings (San-oh et al. 2006), transplanting young seedling (Pasuquin et al. 2008), wider spacing (Thakur et al. 2010a), alternate wetting and drying (Zhang et al. 2009a), and use of organic manure (Yang et al. 2004). All these SRI practices lead to enhanced root and shoot growth and to improvement in their interaction, with characteristics similar to 'super-rice' varieties (Zhang et al. 2009b).

In this study, significant changes were observed in the morphological and physiological characteristics of SRI plants in comparison to flooded rice. SRI practices not only induced greater root growth, but also enhanced root activity, as evident from the greater xylem exudation rates.

Another impact of SRI producing greater and deeper root systems is enhanced water and nutrient uptake, responsible for greater transport of root-sourced cytokinins (Zhang et al. 2009a). These are believed to play a major role in delaying senescence of the leaves. With delayed senescence, higher levels of leaf chlorophyll content are maintained, increasing fluorescence efficiency and photosynthetic rate in SRI plants compared with flooded rice.

Improved root and shoot growth, greater LAI, and a more favourable canopy structure facilitate higher light interception. Such utilization for photosynthesis in SRI rice contributed to larger panicles (more spikelets per panicle), better grain setting (higher percentage of filled grains), heavier individual grains (higher 1000- grain weight), and ultimately higher grain yield than TF.

In conclusion, SRI practices create more favourable soil-water-plant-atmosphere relationships than are achieved under conventional wetland rice production with continuously flooded fields and hypoxic soil conditions. Improvement in grain yield under SRI is attributable to improved morphology and physiological features of the rice plant below and above ground. Against the backdrop of agricultural water scarcity with pressure to produce more grain (more crop per drop), SRI is a promising option for rice growers, more attractive than other, presently-available methods of rice cultivation. SRI methods narrow the gap between genetic potential and in-field yield achievements through management practices.

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