For DRSC members only

DRSC Direct-Seeded Rice Consortium

Partnerships for the future of rice production

2019 Annual Research Report

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Prepared by:
Virender Kumar, Coordinator DSRC

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Abbreviations and Acronyms

CARDI	Cambodian Agricultural Research and Development Institute
CIMMYT	International Maize and Wheat Improvement Center
CNRRI	China National Rice Research Institute
CSISA	Cereal Systems Initiative for South Asia
CAVAC	Cambodia Agricultural Value Chain Program
DAS	Days after sowing
DS	Dry season
DSR	Direct-seeded rice
Dry-DSR	Dry direct-seeded rice
DSRC	Direct-Seeded Rice Consortium
GHG	Greenhouse gas
GDRRI	Rice Research Institute of the Guangdong Academy of Agricultural Sciences
HQ	Headquarters
ICAR	Indian Council of Agricultural Research
ICT	Information and Communications Technology
IFA	International Fertilizer Association
IPI	International Potash Institute
IPNI	International Plant Nutrition Institute
IRRI	International Rice Research Institute
ISARC	IRRI South Asia Regional Centre
MOA	Mode of action
MARDI	Malaysian Agricultural Research and Development Institute
MOALI	Ministry of Agriculture, Livestock and Irrigation
MP seeder	Multi-purpose seeder
NARC	Nepal Agricultural Research Council
NARES	National Agricultural Research and Extension Systems
NRRI	National Rice Research Institute
PARC	Pakistan Agricultural Research Council

PAU	Punjab Agricultural University
PhilRice	Philippines Rice Research Institute
PTR	Puddled transplanted rice
RCER	Research Complex for Eastern Region
R4D	Research for Development
SAGC	Shanghai Agrobiological Gene Center
SMP	Soil metric potential
WateRice	Water Efficient and Risk Mitigation Technologies for Enhancing Rice Production in Irrigated and Rainfed Environments
WCE	Weed control efficiency
Wet-DSR	Wet direct-seeded rice
WS	Wet season
VBU	Visva-Bharti University

Executive Summary

Direct-seeded rice (DSR) has emerged as an efficient, economically viable, and environmentally promising alternative to puddled transplanted rice (PTR) in Asia because it is a cultivation method that saves resources which are becoming increasingly scarce, such as labor and water, and the costs of cultivation. DSR offers both mitigation of climate change (in terms of reducing GHG emissions) and adaptation to its effects (i.e., water shortage, as well as weak and variable monsoon conditions). As a result of its benefits, DSR is widely practiced in many Southeast Asian countries (e.g., Malaysia, Cambodia, Vietnam, Philippines, and Thailand), as well as Sri Lanka in South Asia. China and other South Asian countries (e.g., India, Pakistan, Nepal, and Bangladesh) are also transitioning from PTR to DSR.

Despite its many benefits, there are some risks associated with DSR which limit its wide-scale adoption and the possibility of attaining optimal grain yields using this method. These risks include poor crop establishment and higher weed infestation, which can lead to high yield losses. Other factors that limit DSR from expressing its full potential are limited knowledge of precision water and nutrient management, and the lack of suitable cultivars specifically bred for DSR. In addition, in countries where DSR is widely adopted (e.g., southeast Asian countries), many of the current farming practices are highly inefficient (examples include lack of mechanization for seeding; use of poor-quality farmer-saved seeds with high seeding rates; and inefficient weed, water and nutrient management), and therefore, there is great scope for improving the efficiency and sustainability of DSR through precision crop and resource management practices. Moreover, many weed-related issues have emerged in countries where DSR is widely grown, such as shifts in weed flora toward difficult-to-control weeds – including the evolution of weedy rice; and increased dependence on herbicides, which leads to the risk of evolution of herbicide resistance in weeds.

To address the complex research and scaling issues associated with DSR, IRRI established the ***Direct-Seeded Rice Consortium (DSRC)*** in December 2017, and officially launched on February 6, 2018, at IRRI HQ. DSRC is a public-private multi-stakeholder research for development (R4D) platform on DSR which is convened by the International Rice Research Institute (IRRI). DSRC is a collaborative effort of public and private organizations to improve the environmental and socioeconomic sustainability of rice production systems by developing and optimizing innovations, practices, and methodologies to facilitate wide-scale adoption of mechanized and precise DSR practices in Asia and Africa.

The key research findings of experiments conducted in 2019 in three target countries (India, the Philippines, and Cambodia) are provided below.

2019 Research Highlights

1. INDIA

- IDENTIFYING HIGH-YIELDING AND WEED-COMPETITIVE RICE CULTIVARS SUITABLE FOR DRY-DSR: Rice cultivars were evaluated under DSR at three sites: (a) the IRRI South Asia Regional Centre (ISARC) in Varanasi, Uttar Pradesh; (b) the ICAR-Regional Complex (ICAR-RCER) for Eastern Regional in Patna, Bihar; and (c) the Punjab Agricultural University (PAU) in Ludhiana, Punjab. Key findings are as follows:

  ✓ At the ISARC site, in general, hybrid cultivars produced 21% higher yields than inbred cultivars. Additionally, hybrids were found to be relatively more weed competitive than inbreds because hybrid cultivars suppressed purple rice biomass (used as a surrogate weed to assess the weed competitiveness of cultivars) by 43%, 61%, and 64% more than inbred cultivars when purple rice was sown at 5, 15, and 30 days after rice sowing (DAS), respectively. Overall, four hybrids were observed to be both high yielding and weed suppressive. All of the rice cultivars lodged in DSR except three inbred cultivars, viz. Sarjoo-52, BPTP-5204 and MTU-7029. These results suggest that lodging is more problematic in DSR, especially in hybrids. Therefore, breeding for lodging resistance in DSR cultivars will further improve DSR yields and will also make harvesting easier.

  ✓ At the ICAR-RCER site, overall, the hybrid cultivars studied also produced higher yields than inbred cultivars. Yields with hybrid cultivars were 9% higher under weed-free conditions and 15-120% higher under different durations of weed competition. On average (across all weed competition levels), hybrids yielded 1.0 t ha^{-1}(26%) more than inbreds. These results suggest that, in general, hybrids were more weed competitive and higher yielding than inbred cultivars.

  ✓ At PAU, the objective was to identify which basmati varieties were better suited for DSR conditions. Six basmati varieties were compared under both PTR and dry-DSR. On average, irrespective of variety, rice yield was 17% higher under PTR than under DSR. Basmati rice varieties RYT-3677, Pusa-1121, Pusa-1718, and Punjab Basmati-5 produced similar yields under DSR and PTR, suggesting that these basmati rice varieties are suitable for both DSR and PTR cultivation. In contrast, Punjab Basmati-4 and Pusa Basmati-1637 were not found suitable for DSR conditions, as these cultivars showed yield reductions of 47% and 18%, respectively, in DSR compared to PTR.

- DRIP IRRIGATION – AN EFFICIENT IRRIGATION APPROACH IN DSR-BASED RICE-WHEAT AND RICE-MAIZE SYSTEMS: DSR yield was similar under both drip irrigation and the conventional practice of flood irrigation. However, the irrigation water application using the drip system was 85% lower than the conventional irrigation system. In addition, the DSR yield was 6% higher under sub-surface drip irrigation than under surface drip irrigation. This may be due to higher nutrient and water efficiencies in sub-surface systems than surface drip systems.

- SEED PRIMING/SEED TREATMENT FOR IMPROVING DRY-DSR CROP ESTABLISHMENT AND YIELD: Hydro-priming of seed for 12 to 24 hours did not influence rice yields under DSR. In contrast, seed priming with gibberellic acid (25 and 50 ppm) or potassium nitrate (2%) for 12 to 24 hours increased DSR yields by 6 to13%; this may be attributed to better crop establishment and growth of seedlings when seeds were primed/treated.

- OPTIMIZING TIMING OF FIRST IRRIGATION IN *SOIL MULCH DSR*: *Soil mulching* – also known as sowing in *vattar* (moist) conditions – is a simple management adjustment that uses pre-sowing irrigation followed by shallow tillage and rice sowing. After seeding, the first irrigation is generally delayed for about 2 weeks. Together, these practices reduce weed pressure while also reducing early irrigation requirements by conserving soil moisture. Moisture conservation facilitates early planting of DSR (i.e., planting 2 to 3 weeks before the onset of the monsoon) when water demand for the rice is otherwise high due to hot and dry weather conditions. Early planting, in turn, reduces the risk of stand mortality caused by inundating rains during the early phases of crop growth. There is a lack of systematic research examining how long first irrigation can be delayed after sowing in soil mulch DSR. This study found that in DSR with soil mulching, the first irrigation can be delayed until 21 days after sowing without compromising rice yield by conserving soil moisture (a soil mulch effect). Soil mulching also reduced early weed pressure (i.e., weed density and weed biomass were ~71-74% and 62% lower, respectively) when irrigation was delayed until 21 days after sowing as compared to applying irrigation immediately after sowing. This also resulted in an irrigation water savings of 12%. These results suggest that soil mulching is a viable risk-reducing agronomic practice that reduces weed pressure and saves irrigation water without impacting rice yields.

- DEVELOPING WEED MANAGEMENT SOLUTIONS: Weed control is considered one of the principal obstacles to attaining the full yield potential of the DSR method. In DSR, reliance on herbicides for weed control has increased because of the higher weed infestation in DSR, rising wages for labor, and lack of availability of labor for hand-weeding; this contributes significantly to the risk of evolution of herbicide resistance. Therefore, it is important to identify herbicide options with different modes of action (MOAs) that can provide effective weed control in DSR so that farmers can rotate herbicides with different MOAs and use them sustainably for longer, thereby avoiding/delaying the evolution of herbicide resistance. The results demonstrated sequential application of pre-emergence herbicides [(pendimethalin or oxadiargyl) followed by (*fb*) post-emergence application of herbicides [bispyribac-sodium or a tank-mix of fenoxaprop-p-ethyl (Ricestar) + ethoxysulfuron (Sunrice) or a pre-mix of penoxsulam + cyhalofop-butyl (Vivaya), or pre-mix of florpyrauxifen-benzyl + cyhalofop-butyl (Novlect)] provided effective weed control in DSR. Among post-emergence options, a tank mix of Novlect (pre-mix) + Ricestar (fenoxaprop-ethyl)] [combination of three MOAs] – provided effective weed control and produced yield similar to standard check treatments of sequential application of pre-emergence followed by post-emergence herbicides. In addition, fenoxaprop +ethoxysulfuron and penoxsulam + fenoxaprop also provided effective weed control.

2. IRRI HQ, PHILIPPINES

- OPTIMIZED SEED RATE FOR BOTH WET- AND DRY-DSR IDENTIFIED: Farmers in Southeast Asia use high seeding rates in DSR, ranging from 100-350 kg ha^{-1}. High seed rate is considered one of the bottlenecks to adoption of good quality seeds of inbred or hybrid cultivars in DSR. Our results demonstrated that there is enormous scope for reducing the seed rate in DSR, depending on the optimal conditions available in farmers' fields (e.g., good leveling, good water control, good quality seeds, reducing the risks posed by biotic and abiotic factors, etc.) and the variety (high tillering or low tillering). Under optimal conditions the following results were observed:

    - **In dry-DSR,** the yield did not differ with seeding rates of 20 to 200 kg ha^{-1}in the dry season, whereas, in the wet season, the yield did not differ with seeding rates of 20 to120 kg ha^{-1} but declined at higher seeding rates (200 kg ha^{-1}).
    - **In wet-DSR,** in both the dry and wet seasons, irrespective of the seeding rate, the DSR yield was higher in line-sown DSR than in broadcast DSR. In the wet season, the DSR yield did not vary with seeding rates of 20 to 60 kg ha^{-1} but declined at seeding rates of ≥ 80 kg ha^{-1}. In the dry season with line-sown DSR, the yield did not differ when seeding rates of 20 to120 kg ha^{-1} were used but declined by 16-21% at 200 kg ha^{-1}. With broadcast DSR, yields were more variable, and the best yields were observed at seeding rates in the range of 40 to 80 kg ha^{-1}.

- HIGH-YIELDING AND WEED-COMPETITIVE RICE CULTIVARS SUITABLE FOR DSR: Results demonstrated that the performance of hybrids in terms of yield was variable across seasons and years, but hybrids consistently suppressed purple rice biomass (used as a surrogate weed) more than inbreds, suggesting that hybrids had higher weed suppressive ability than inbred cultivars. In 2019, overall yields of hybrid and inbred cultivars did not differ during the wet season but were lower in hybrids than inbred cultivars in the dry season. These results are the opposite of the results observed in 2018. Possible reasons for the variable results in these yields are discussed in the report. Path analysis suggests that early biomass accumulation around 30 DAS by rice cultivars is one of the major traits associated with weed competitiveness. Traits such as plant height, tiller number, percentage canopy cover, relative growth rate, etc., appeared to indirectly affect weed suppression by contributing to early rice biomass accumulation. These results suggest that high early biomass accumulation by rice cultivars could be an important criteria for breeding rice genotypes for weed competitiveness, and using this trait, cultivars can be assessed for their weed competitiveness under weed-free conditions.

- POTENTIAL BENEFITS AND RISKS OF HERBICIDE-TOLERANT RICE (CLEARFIELD RICE®) TECHNOLOGY EVALUATED: Herbicide-tolerant (HT) technology can overcome weed-related issues associated with DSR and may therefore facilitate adoption of DSR. Despite the advantages of this technology, there are some potential risks associated with HT-technology that should be fully understood prior to commercialization. In 2019, the potential benefits and risks of Clearfield Rice® technology – one of the HT-Rice technologies that has been commercialized globally in various countries – were studied under Philippine conditions. The results of this study showed that Clearfield technology would be effective in managing weed problems in DSR, including difficult-to-control weeds such as *weedy rice, Ischaemum rugosum, and Leptochloa chinensis*.

We did not observe any carryover effect/phytotoxicity of Clearfield rice herbicides [Pre-mix imazapyr + imazapic in 1:3 ratio as pre-emergence (ONDUTY) and in 3:1ratio as early post-emergence (KIFIX)] on normal rice cultivars (non-Clearfield rice) when planted 77 and 96 days after application. These results suggest that after harvest of Clearfield rice, farmers can, if they are interested, plant their normal rice varieties without any risk of phytotoxicity from Clearfield herbicides.

We also studied the potential risk of phytotoxicity on the neighboring rice field planted with normal varieties due to drift from the KIFIX herbicide (one of the Clearfield rice technology herbicides). We simulated drift by applying KIFIX at a reduced rate of 6.25% and 12.5% of the recommended rate for Clearfield rice varieties at three growth stages (10 DAS, 35 DAS, and 60 DAS) of the rice variety (RC-18) widely cultivated in the Philippines. Both the KIFIX rate and the time of application (growth stage of crop) significantly affected rice yield. Irrespective of crop stage, the yield of the normal rice variety was reduced by 35% and 54% with applications of 6.25% and 12.5% of the recommended rate of KIFIX, respectively. Also, irrespective of rates, the highest yield reduction occurred when KIFIX was applied at a later stage (60 DAS) than at an early stage (10 DAS); yield reductions of 25%, 45%, and 62% compared to non-treated control were observed when KIFIX was applied at 10, 35, and 60 DAS, respectively. These results suggest that drift from KIFIX application can impose a risk on rice grown by neighboring farmers planting normal rice varieties. In the upcoming season, we will also assess the drift risk associated with ONDUTY, another Clearfield herbicide, so that these data can assist policy makers in making decisions concerning which herbicides should be recommended in the Philippines.

- DEVELOPMENT OF INTEGRATED SOLUTIONS FOR WEEDY RICE MANAGEMENT: Based on the 2019 study conducted in farmers' fields in Iloilo, Philippines, oxadiazon in combination with flooding for 10 days prior to rice sowing has been found effective in suppressing weedy rice density by 70% in wet-DSR. This also resulted in a 34% increase yield in the oxadiazon + flood treatment as compared to farmers' existing practice. In the second experiment, the IWM package (land preparation, certified seed free of weed seeds, line sowing to facilitate early roughing, early flood establishment, etc.) also suppressed the weedy rice population by 49-60% and enhanced rice yield by 16% compared to farmers' practice.

- SEED TREATMENT SOLUTIONS: Seed treatment solutions (insecticide- or fungicide-based) improved the yield of DSR as compared to no seed treatment. However, pest incidences were low in this experiment, suggesting that these seed treatment solutions may have some plant growth-promoting effect on the crop, and this may have had a positive impact on yield.

- OPTIMIZING DRIP IRRIGATION FOR DIVERSE BENEFITS: In 2019, we conducted a study to optimize the irrigation scheduling criteria for drip irrigation and to quantify the effect on yield and water savings in DSR. Since this experiment was conducted in the wet season, yield was not affected by the type of drip system (surface or sub-surface) or by the three irrigation scheduling thresholds at 70%, 100%, and 130% of crop demand. Application of irrigation water was 11% lower in the sub-surface drip system than in the surface drip. Overall, the total water productivity (irrigation + rain) ranged from 0.52 to 0.71 kg m^{-3} in the drip irrigation, whereas in PTR, it was 0.25 kgm^{-3}.

- IRON COATING OF RICE SEED TECHNOLOGY EVALUATED IN TROPICAL ASIA: Iron coating of rice seeds can overcome the risk of seed drift in wet-DSR under flooded conditions caused by rain during the early stage of crop establishment. It can also reduce the occurrence of seed-borne diseases and minimize the incidence of birds eating seeds. It may also facilitate adoption of modified water seeding, hence eliminating the need for forced drainage, which is otherwise needed in wet-DSR to ensure good crop establishment. This technology has been developed and tested in Japan, but knowledge of its performance in tropical Asia is lacking. In 2019, with JFE Steel Corporation, a protocol for the preparation of iron-coated rice seed suitable for tropical Asian conditions was developed for both smallholders (manual method) and for commercial level seed coating (mechanical method). In addition, the performance of the iron coating technology was assessed under wet- and water-seeding conditions. Under optimal conditions (well drained), the yield of iron-coated seed and non-coated pre-germinated seed under wet-DSR conditions was the same. However, under water-seeding (continuous flooding for first two days), iron-coated seeds resulted in an 11% higher yield compared to pre-germinated non-coated seeds, suggesting that iron coating of rice seeds can be used for both wet-seeding and water-seeding. We also evaluated the effect of iron-coating ratio and duration of water-seeding/flooding on crop establishment to optimize water-seeding duration. Results showed that water-seeding with 2 days of early flooding is feasible with iron coating, as crop establishment of iron-coated seeds was not affected with 2 days of flooding but adversely affected if flooding duration extended to 4 and 6 days. Water-seeding with 2 days of early flooding also inhibited weed establishment and their growth, suggesting that shorter duration early flooding through water-seeding may also reduce weed problems.

3. CAMBODIA

In Cambodia, 90% of the rice is established using broadcast DSR, but productivity and profitability have remained low, mostly due to the use of poor quality farmer-saved seed; high seeding rates (150-330 kg ha^{-1}); poor weed, water, and nutrient management; higher lodging associated with high seed rate; and low adoption of mechanization for crop establishment. Mechanized DSR with low seeding rates (60-80 kg ha^{-1}) will enable farmers to use good quality seeds free of weed seeds and diseases, and thereby enhance productivity and profitability. However, data on the value of good quality seeds (good seed versus farmers' saved seed), seeding rate, and establishment methods (broadcast versus mechanized line sowing) that could be used to convince farmers of the potential positive impacts on their crop yield and profitability are limited. Therefore, the following efforts were made to quantify these impacts:

- IMPACT OF GOOD QUALITY SEEDS ON DSR YIELD: Rice yields were 23-26% and 12-19% higher when good quality rice seeds were used as compared to farmers' saved-seed during the early wet and main wet season 2019, respectively. Also yield was similar or 13% higher when rice was established using a seed drill when compared to broadcast DSR.

- IMPACT OF SEED RATE AND ESTABLISHMENT METHOD ON DSR YIELD: Response of seed rate in the range of 60-120 kg ha^{-1} was assessed on rice yield in broadcast and drill dry-DSR. A seed rate of 80 kg ha^{-1} was found to be optimal and produced the highest yield; yields using seeding rates of 60 and 120 kg ha^{-1}were10-13% lower in comparison. In addition, the yield was 9% higher when rice was established with a mechanized seed drill than with the broadcast method.

These results suggest that mechanized DSR sown at lower seeding rates with good quality seed can improve the productivity and profitability of Cambodian farmers. Similar results were observed by our other DSRC members and partners in Cambodia (CAVAC, Syngenta Foundation, Agri-Smart, and Sydney University) and they are now promoting mechanized DSR in the country.

Current Members of DSRC

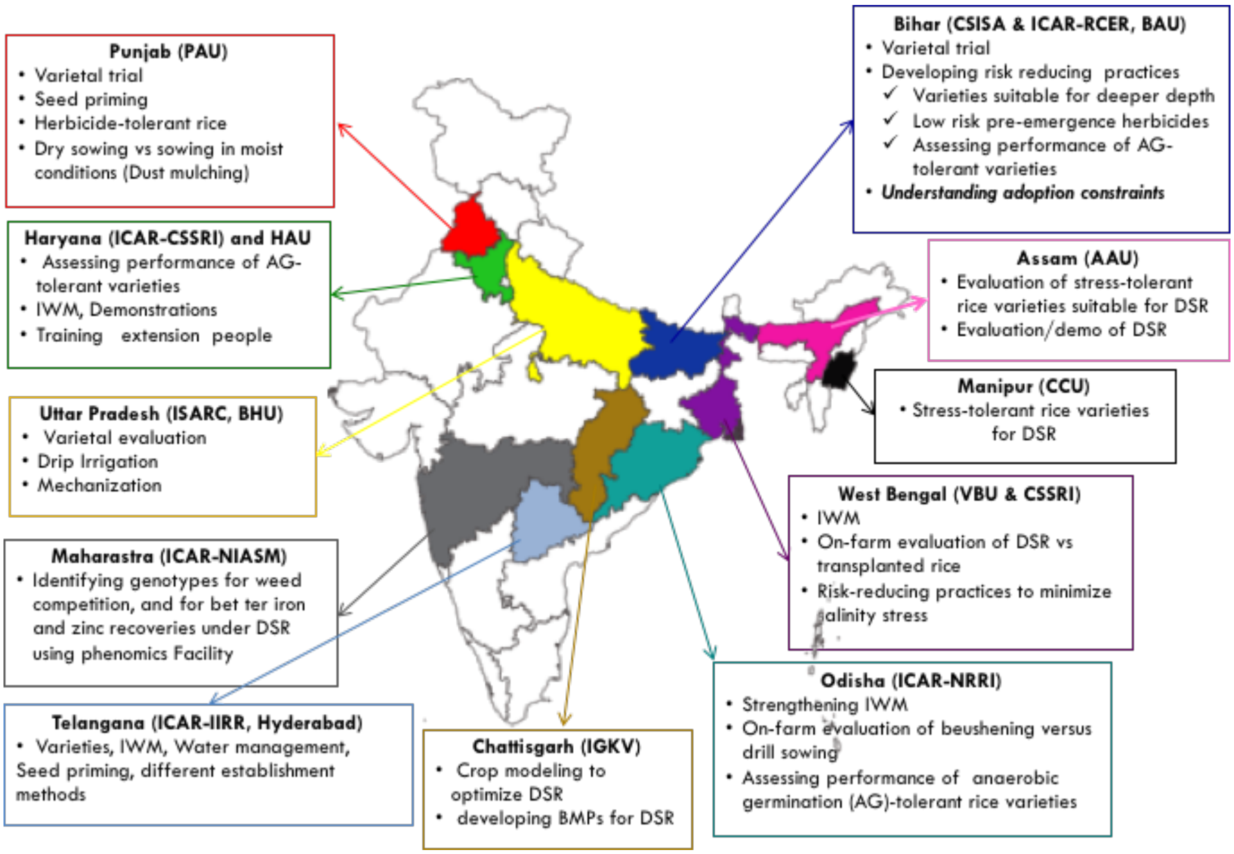
Sr. No.	Name of the organization	Membership type	Link to website
01	BASF	Platinum	https://agriculture.basf.com/global/en.html
02	Bayer Crop Science	Gold	https://www.cropscience.bayer.com/
03	Jain Irrigation Systems Ltd.	Gold	https://www.jains.com/
04	Corteva Agriscience	Gold	https://www.corteva.com/
05	JFE Steel Corporation	Gold	https://www.jfe-steel.co.jp/en/
"06	Atlas Fertilizer Corporation	Silver	https://www.atlasfertilizer.com/en_US
07	Kilang Beras Seri Merbok Sdn. Bhd.	Silver	http://www.serimerbok.com.my/
08	APV – Technische Produkte GmbH	Associate	https://www.apv.at/
09	African Agricultural Technology Foundation (AATF)	Green	https://www.aatf-africa.org/
10	Cambodia Agricultural Value Chain Program (CAVAC)	Green	https://cavackh.org/
11	Cambodian Agriculture and Development Institute (CARDI)	Green	http://www.cardi.org.kh/
12	China National Rice Research Institute (CNRRI)	Green	http://www.chinariceinfo.com/en/
13	Indian Council of Agricultural Research (ICAR)	Green	https://icar.org.in/
14	International Fertilizer Association (IFA)	Green	https://www.fertilizer.org/
15	International Plant Nutrition Institute (IPNI)	Green	http://www.ipni.net/
16	International Potash Institute	Green	https://www.ipipotash.org/en/index.php
17	Malaysian Agricultural Research and Development Institute (MARDI)	Green	https://www.mardi.gov.my/
18	Ministry of Agriculture, Livestock and Irrigation (MOALI), Myanmar	Green	https://www.moali.gov.mm/en
19	Nepal Agriculture Research Council (NARC)	Green	http://narc.gov.np/
20	Pakistan Agricultural Research Council (PARC)	Green	http://www.parc.gov.pk/index.php/en/
21	Philippine Rice Research Institute (PhilRice)	Green	http://www.philrice.gov.ph/
22	Rice Research Institute of Guangdong Academy of Agricultural Sciences (GDRRI)	Green	http://www.gdaas.cn/english/
23	Shanghai Agrobiological Gene Center (SAGC)	Green	http://www.sagc.org.cn/brief/index.jhtml
24	Syngenta Foundation	Green	https://www.syngentafoundation.org/
25	Thai Rice Department	Green	http://www.ricethailand.go.th/web/
26	The University of Sydney, Australia	Green	https://sydney.edu.au/

Research Report (2019)

1. India

The Indian Council of Agricultural Research (ICAR) is a green member of DSRC. Under the umbrella of ICAR, the DSRC carried out strategic research trials at various ICAR research institutions and state agricultural universities (SAUs). In 2019, DSRC research was conducted in collaboration with the following national institutions: ICAR-National Rice Research Institute (NRRI), Cuttack, Odisha; ICAR-Research Complex for Eastern Region (ICAR-RCER), Patna, Bihar; Punjab Agricultural University (PAU), Ludhiana, Punjab; and Visva-Bharti University, Shantiniketan, West Bengal. In addition, a direct-seeded rice field laboratory was established at the IRRI South Asia Regional Centre (ISARC) in Varanasi, Uttar Pradesh.

In 2019, a strong DSR research network was established with additional research institutions in India to address the complex issues of DSR (see the inset below for a list of these research centers. Strategic research programs, letters of agreement, and funding, have been finalized with these new institutions. Alongside the institutions mentioned above, these new centers will begin conducting state- or region-specific strategic research trials on DSR from Kharif (wet season) 2020.



Inset: DSR research network in India established under DSRC

Key results of the research trials conducted in India during the 2019 wet season are detailed below.

1.1. Varietal Evaluation to Identify Suitable Rice Cultivars for DSR in Different Geographies

Significant progress has been made in agronomy of DSR and further refinement of this cultivation method remains important. However, identifying cultivars suitable for DSR conditions is equally critical factor in improving the potential of DSR systems. Cultivars with the following characteristics are desirable in DSR: high-yielding with shorter duration; weed suppressive; resistant to insect pests, diseases and lodging; and adapted to mild stresses, including moisture and nutrient stresses. In India, during the 2019 wet season, experiments were conducted in Uttar Pradesh, Bihar, and Punjab with the objective of identifying high-yielding and weed-suppressive rice cultivars for dry-DSR.

Experiment 1: EVALUATING THE PERFORMANCE OF INBRED AND HYBRID RICE CULTIVARS UNDER DRY-DSR CONDITIONS FOR EASTERN UTTAR PRADESH, INDIA

Location of the study: This study was conducted at the DSR Field Laboratory established in the IRRI South Asia Regional Centre (ISARC), in Varanasi, Uttar Pradesh (25.303952 N Latitude, 82.946873 E longitude, and 70 m above mean sea level).

Treatments: A total of 14 of the most commonly available rice cultivars (hybrids and inbreds) in eastern Uttar Pradesh were used in this experiment.

Cultivar ID	Types/duration	Cultivar ID	Types/duration
V1	Inbred/Short (115-120 d)	V8	Hybrid/Medium
V2	Inbred/Short	V9	Hybrid/Medium
V3	Hybrid/Short	V10	Hybrid/Medium
V4	Hybrid/Medium (125-135 d)	V11	Hybrid/Medium
V5	Hybrid/Medium	V12	Inbred/Long (> 135 d)
V6	Inbred/Medium	V13	Inbred/Long
V7	Inbred/Medium	V14	Inbred/Long

The following hybrid (Bayer Crop Science and Corteva Agriscience) and inbred (public sector) rice cultivars were used in this experiment:

- **Hybrid cultivars:**
  - Bayer: Arize 6129 Gold, Arize6444 Gold, AZ8433DT
  - Corteva: XRA37923, XRA38967, XRA 37741, XRA27936
- **Inbred cultivars:**
  - DRR Dhan-44, Sarju-52, Sahbhagi Dhan, BPT-5204, MTU-7029, Super Moti, Kalanamak

Experimental design: Randomized complete block with three replications

Plot size: 9.5 m x 3.25 m

Date of sowing: June 14, 2019

Method:

A total of 14 rice cultivars (7 hybrids and 7 inbreds) were sown on June 14, 2019 at the IRRI-South Asia Regional Centre research farm in Varanasi. The crop was sown at a seed rate of 20 kg ha^{-1} using a limit-plot multi-crop planter and 20-cm row spacing. For field preparation, pre-sowing irrigation was applied on June 10, then the field was tilled at optimum soil moisture (hereafter, referred to as the *vattar* condition). Fertilizer N, P_2O_5, K_2O, and $ZnSO_4$ @ 120, 60 and 30 kg ha^{-1} were applied to the experimental plot through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively, for all treatment plots. Nitrogen was applied in 3 splits (1/3 N as basal and the remaining 2/3 in two equal splits at active tillering and panicle initiation). The full dose of phosphorus and potash was applied as basal during the final land preparation. In addition, zinc as $ZnSO_4.7H_2O$ @ 25 kg ha^{-1} was also applied as a basal dose at the time of final field preparation.

To assess the weed competitiveness of these cultivars, purple rice (a surrogate weed) was planted in a one meter row between two lines of rice at 5, 15 and 30 DAS at four locations for each time in each plot. In addition, 3 m x 1 m microplots consisting solely of purple rice were established separately as a control for recording the growth of purple rice without competition from cultivated rice for each timing (5, 15 and 30 DAS). For each time, the planted purple rice was harvested at 60 and 100 days after planting and the oven-dried biomass was recorded. The observations on various phenological stages of rice, such as plant height and the number of tillers m^{-2}, were recorded from the earmarked area for periodic sampling. For weed management in all DSR plots, pendimethalin 1.0 kg ai ha^{-1} was applied as a pre-emergence on the same day as sowing followed by a tank mix of bispyribac-sodium 20 g ai ha^{-1} and pyrazosulfuron-ethyl 20g ai ha^{-1} as a post-emergence application at 26 DAS to manage complex weed flora. The yield attributing characters viz. number of panicles m^{-2}, grains per panicle, 1000-grain weight (test weight), and the yield from individual plots were also recorded. For water and pest management, best management practices were followed throughout the cropping season.

Results:

The results showed that under dry-DSR, medium- and short-duration rice hybrids performed better than medium- or short-duration inbred rice cultivars, or long-duration inbred cultivars, except for V14 (Fig. 1). Among all cultivars, medium-duration rice hybrid cultivars V10 and V11 produced the highest yields (~7.4 t ha^{-1}); these yields were on par with the yields of V5 (medium-duration hybrid), V3 (short-duration hybrid) and V14 (long-duration inbred) which ranged from 6.5 to 7.0 t ha^{-1}, but were higher than the rest of the cultivars (Fig. 1). The yields of these cultivars were followed by the other medium-duration hybrids, V4, V8, and V9, with yields ranging from 6.1 to 6.3 t ha^{-1}. The lowest yield was recorded in the long-duration inbred cultivars, V12 and V13, and the shorter duration inbred cultivar, V1, with yields ranging from 4.2 to 5.2 t ha^{-1}. Almost all rice cultivars lodged except three inbred rice cultivars viz. Sarjoo-52, BPTP-5204 and MTU-7029. These results suggest that lodging is more problematic in DSR, and therefore, cultivars with lodging resistance will further improve DSR yields and will also make harvesting easier.

Overall, based on contrast analysis comparing hybrid versus inbred performance, hybrids showed a yield advantage of 1.4 t ha^{-1} (21%) compared to inbred cultivars (Fig. 2)

The results also clearly demonstrated that hybrid rice cultivars were more weed suppressive than inbred rice cultivars as purple rice biomass was lower under hybrid than under inbred cultivars (Fig. 3). On average, purple rice biomass was 43%, 61%, and 64% lower under hybrid rice cultivars compared to inbred rice cultivars for purple rice sown at 5 DAS, 15 DAS and 30 DAS, respectively (based on contrast analysis, p= <0.0001 for all timings; see Fig. 3). Among rice cultivars, in the early weed competition scenario, rice hybrids V8, V9, V10, V11, and V3, and rice inbred V2 were more weed competitive and had the lowest purple biomass at 100 DAS. When weed competition was delayed from 5 DAS to 15 DAS or 30 DAS, in addition to the above cultivars, rice hybrids V4 and V5 were also found to be weed competitive. In summary, rice hybrids such as V10, V11, V3, and V5 were both high yielding and more weed competitive than others. However, rice inbreds, such as V14, were high yielding but not weed competitive.

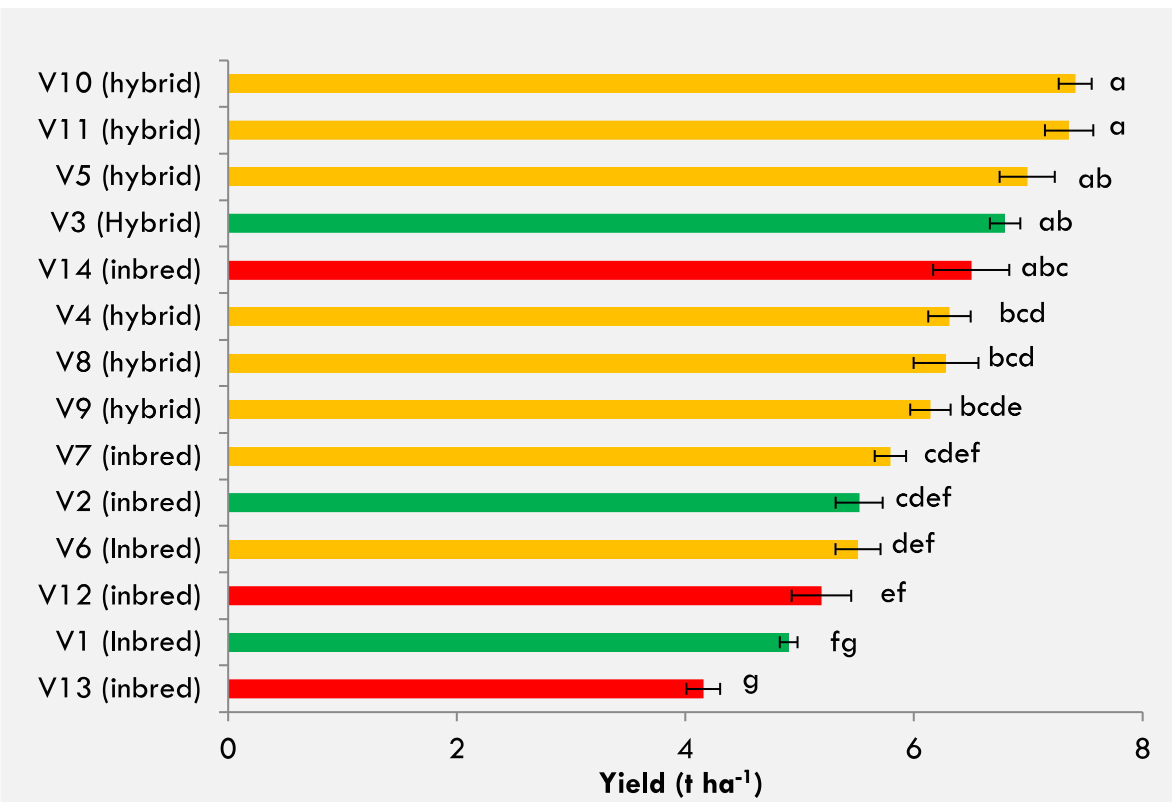


Figure 1. Rice grain yield of 14 rice cultivars under dry-DSR conditions during the 2019 wet season at ISARC in Varanasi, Uttar Pradesh.

**Different letters indicate significant difference in treatments using Tukey's HSD test.*

*** Green, orange, and red bars indicate short-, medium- and long-duration cultivars, respectively.*

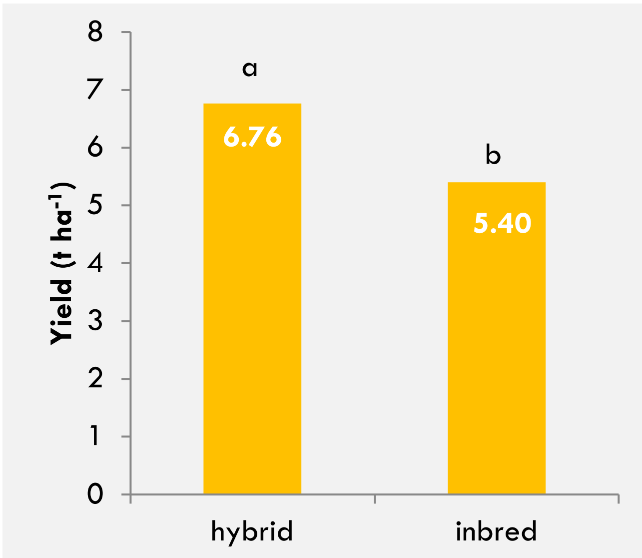
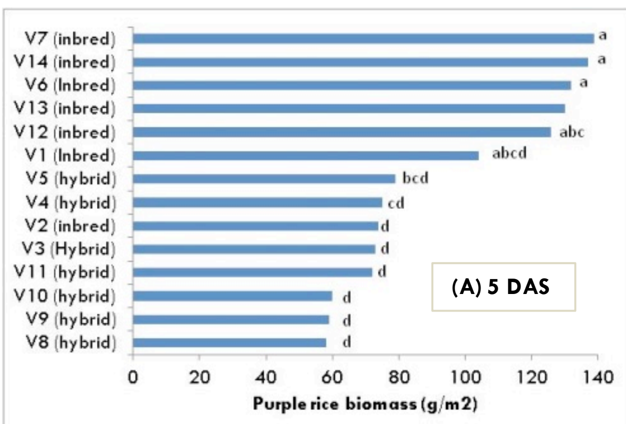
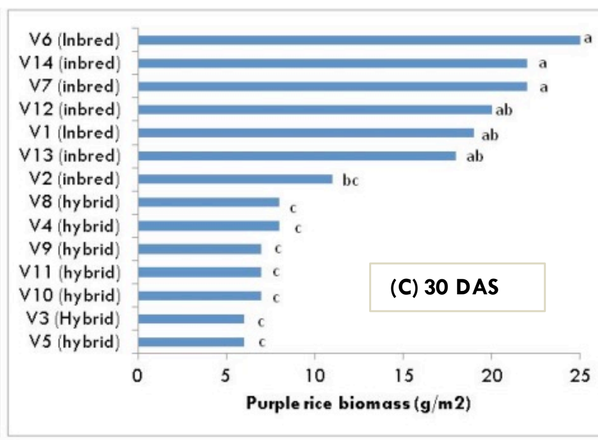


Figure 2. Contrast analysis for rice grain yield of hybrid versus inbred cultivars under dry-DSR during the 2019 wet season at ISARC, Varanasi, Uttar Pradesh.

**Different letters indicate significant difference in treatments using Tukey's HSD test at 5% level of probability.*





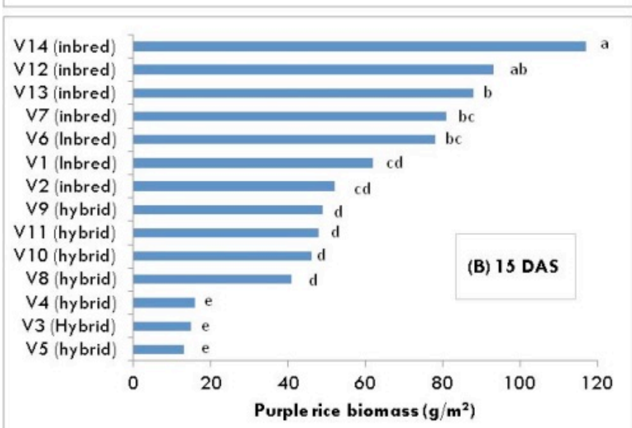
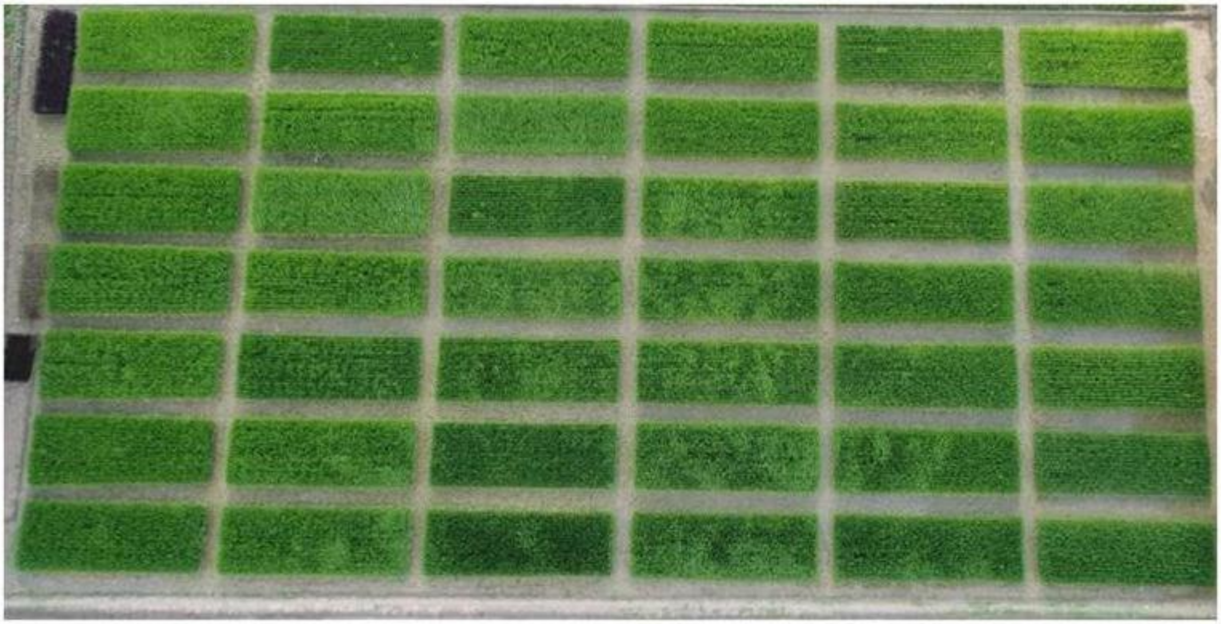


Figure 3. Purple rice biomass under different rice cultivars at 100 days after rice sowing (DAS) sown at 5 DAS (A), 15 DAS (B), and 30 DAS (C).

**Different letters indicate significant difference in treatments using Tukey's HSD test at 5% level of probability.*



Field view of rice varietal evaluation experiment at ISARC, Varanasi, India

Experiment 2: IDENTIFYING HIGH-YIELDING AND WEED-COMPETITIVE RICE CULTIVARS (INBRED AND HYBRID) UNDER DRY-DSR CONDITIONS FOR BIHAR STATE, INDIA

This experiment was conducted in collaboration with the Cereal Systems Initiative for South Asia (CSISA, www.csisa.org) and ICAR-RCER, Patna, to evaluate the performance of the most commonly available hybrid and inbred rice cultivars in Bihar in terms of yield and weed competitiveness under dry-DSR conditions.

Collaborating scientists: Dr. S.P. Poonia and Dr. R.K. Malik, CIMMYT-India; Dr. J.S. Mishra, ICAR-Research Complex for Eastern Region, Patna (ICAR-RCER)

Location of study: This study was conducted at the Cereal Systems Initiative for South Asia (CSISA) Research Platform, located at the experimental farm in the ICAR-Complex for the Eastern Region (ICAR-RCER) in Patna, Bihar, India (25° 24.912'–25° 25.971'N Latitude and 85° 03.536'–85° 03.624'E Longitude).

Treatments:

Main plot: Duration of weed competition (4)

- From 5 DAS to maturity
- From 15 DAS to maturity
- From 30 DAS to maturity
- Free from weed competition (weed-free)

Note: Purple rice was used as a surrogate weed to ensure uniform planting density in all plots. Purple rice was sown in the middle of rice rows at 5-cm plant-to-plant distance 5, 15, and 30 days after rice sowing (DAS) to create different durations of weed competition.

Sub-plot: Rice cultivars (11)

Cultivar ID	Types/duration	Cultivar ID	Types/duration
V1	Hybrid/Short (115-120 d)	V7	Hybrid/Medium (125-135 d)
V2	Inbred/Short	V8	Hybrid/Medium
V3	Hybrid/Medium (125-135 d)	V9	Inbred/Medium
V4	Hybrid/Medium	V10	Inbred/Long ((>135 d)
V5	Hybrid/Medium	V11	Inbred/Long
V6	Hybrid/Medium		

The following rice hybrids (from Bayer Crop Science and Corteva Agriscience) and inbreds (public sector) were used in this experiment:

- Bayer hybrids: Arize 6129 Gold, Arize6444 Gold, AZ8433DT
- Corteva hybrids: XRA37923, XRA38967, XRA 37741, XRA27936
- Public sector inbreds: Sarju-52, Sahbhagi Dhan, BPT-5204, MTU-7029

Experimental design: Split-plot with three replications

Date of sowing: June 18, 2019

Method:

All 11 cultivars, which vary in crop duration and type (hybrid or inbred) (see treatment list for details), were sown on June 18, 2018. The sub-plot size was 4.8 m x 7.5 m. Seeding was done using a limit plot planter specifically designed for varietal evaluation trials, using a seed rate of 25 kg ha^{-1} with 20-cm row spacing. Purple rice was sown in trays at 5, 15 and 30 days after rice seeding (DAS), then 7- to10-day-old seedlings of purple rice were transplanted between rice rows in the respective weed competition duration plots. Fertilizer N, P2O5 and K2O @ 120, 60 and 30 kg ha^{-1} were applied in the experimental plots through urea, DAP, and MOP, respectively. Nitrogen @ 120 kg ha^{-1} through urea was applied in 3 splits (22.5 kg ha^{-1} through DAP as basal and the remaining N applied in two equal split doses at active tillering and panicle initiation). The full dose of P and K was applied as basal during seeding. In addition, zinc as ZnSO4.7H2O @ 25 kg ha^{-1} was also applied as basal. For weed management, a tank mix of bispyribac (25 g ai ha^{-1}) + (chlorimuron + metsulfuron) (4 g ai ha^{-1}) was applied as an early post-emergence herbicide at 15 DAS followed by 1-2 spot hand weeding.

Results:

The results showed that both rice cultivar and duration of weed competition significantly affected rice grain yield (Table 1). Irrespective of cultivars, rice grain yield declined with increased duration of weed competition with purple rice (surrogate weed) with a maximum yield of 5.9 t ha^{-1} under weed-free conditions (no competition), and a minimum yield of 3.0 t ha^{-1} when purple rice was allowed to compete with rice for the longest duration (from 5 DAS to maturity). Compared to the weed-free condition, rice yield declined by 49%, 22%, and 10% when purple rice competed with rice cultivars from 5 DAS, 15 DAS, and 30 DAS to maturity, respectively.

Irrespective of the duration of weed competition, yield was affected by rice cultivars (Table 1; ANOVA). Among the rice cultivars, rice hybrids V5 and V6 produced the highest grain yield (~ 6.2 t ha^{-1}) followed by rice hybrids V3, V7, and V8 (5.0 to 5.1 t ha^{-1}), and rice inbreds/hybrids V2, V9, V4 and V11 (4.1 to 4.5 t ha^{-1}). The lowest yields were observed in rice hybrid V1 and inbred V10 (3.6 t ha^{-1}).

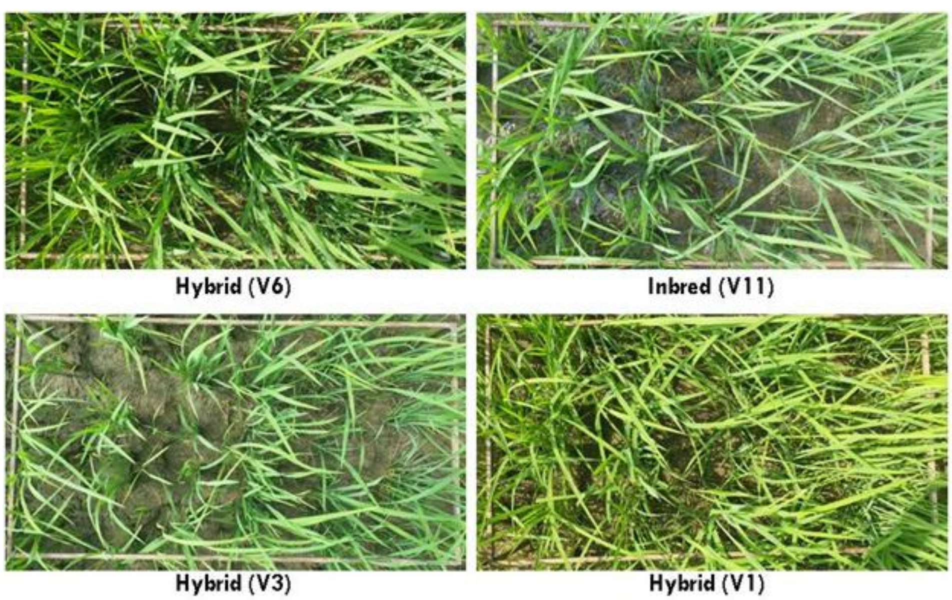
The weed competition x cultivar interaction was significant, suggesting that varietal performance varied with the duration of weed competition (Table 1, ANOVA Table). Two hybrids (V5 and V8) were least affected by weed competition and produced nearly similar yields, both under weed-free conditions and under weed competition of different durations. Other cultivars were more affected by weed competition, and results varied depending on the duration of weed competition. When weed competition was implemented from 5 DAS to maturity, yield losses due to weed competition were lowest (14-17%) in the medium-duration rice hybrid cultivars V5 and V8, followed by medium-duration rice hybrid V6 with a 38% yield loss, suggesting these cultivars are less affected by early weed competition than the rest of those tested. Among rice cultivars V1, V3, V4, and V7 (short- and medium-duration hybrids), and V2 and V9 (short- and medium-duration inbred cultivars), yield reduction was 46-63%. In the long-duration inbred cultivars (V10 and V11), yield reduction was 80-82%, suggesting that these varieties are highly susceptible to early weed competition. In terms of yield, rice hybrid V5 produced the maximum yield (5.77 t ha^{-1}), followed by rice hybrids, V6 and V8 (4.34 to 4.55 t ha^{-1}); the lowest yields were observed in rice inbreds V10 and V11 (1.0 to 1.2 t ha^{-1}) under early weed competition (5 DAS to maturity). When purple rice competition with rice cultivars was delayed from 5 DAS to 15 DAS, losses due to weed competition were reduced in most of the cultivars; yield reductions ranged from 6 to 22% in 8 out of 11 cultivars. In the remaining three cultivars (V1, V4, and V10), losses were around 40%. In the case of delayed weed competition (15 DAS to maturity), the highest yields were observed in rice hybrids V6 (6.6 t ha^{-1}) and V5 (5.9 t ha^{-1}), followed by rice hybrids V3 and V7 (5.1 to 5.3 t ha^{-1}); rice inbreds V11, V9, and V2; and hybrid V8 (4.3 to 4.6 t ha^{-1}). The cultivar with the lowest yield was rice hybrid V1 (2.7 t ha^{-1}). When weed competition was further delayed to 30 DAS, yield losses due to weed competition were only in the range of 3-8% in rice hybrids V3-V8 and 11% in rice hybrid V1. In rice inbreds the yield loss was 6% in V9, 18-19% in V2 and V11, and 26% in V10. Under weed-free conditions, the maximum yield of 6.98 t ha^{-1} was recorded in rice hybrid V6, which did not differ from the yield of rice hybrids V3, V4, V5, and V7, but the recorded yield was higher than the rest of the cultivars.

Based on contrast analysis comparing hybrids over inbreds at all weed competition levels, hybrids performed better than inbred cultivars (Fig. 4). On average (across all weed competition levels), hybrids yielded 1.0 t ha^{-1} (26%) more than inbreds. Yield advantages in hybrid compared to inbred cultivars were 1.2 t ha^{-1} (120%), 0.6 t ha^{-1} (15%), 1.1 t ha^{-1} (24%), and 0.5 t ha^{-1} (9%)

under early (5 DAS), medium (15 DAS), and late weed competition (30 DAS), and under weed-free conditions, respectively.

When purple rice was sown at 5 DAS, the biomass of purple rice at crop maturity was influenced by rice cultivars (Table 2). The purple rice biomass was lowest under rice hybrids V5 (86 g m^{-2}) followed by rice hybrids V8 (180 g m^{-2}) and V7 (231 g m^{-2}) and rice inbred V2 (255 g m^{-2}), which did not differ from V5. Rice hybrids V1, V3, and V4 and rice inbred V11 provided medium-level suppression of purple rice with biomass 287 to 295 g m^{-2}. Purple rice biomass was highest under rice inbreds V9 and V10 (454 to 530 g m^{-2}), suggesting that these were the least weed suppressive. These results suggest that rice hybrids V5, V7, and V8 were more weed suppressive. Among inbreds, V2 was the most weed suppressive, followed by V11. Rice inbreds V9 and V10 were the least weed suppressive of all cultivars. Purple biomass was not affected by cultivars when purple rice competition was delayed from 5 DAS to 15 or 30 DAS. Irrespective of weed competition timing, hybrids V5, V7, and V8 were the most weed suppressive, followed by V1-V4 and V6 and inbreds V9, V10, and V11, which were less weed suppressive.

These results suggest that medium-duration hybrid rice cultivars V5 and V6 were both high-yielding and weed-competitive cultivars. Rice hybrid V8 was also weed competitive, but its yield potential under weed-free conditions was comparatively low than other high-yielding cultivars. Therefore, this hybrid could be a good option where weed control is expected to be sub-optimal but may be less suitable where good weed management is possible. Other high-yielding rice cultivars observed were V3, V4, V7 (medium-duration hybrids), V11 (long-duration inbred), and V9 (medium-duration inbred), but these were found to be less weed competitive. These high-yielding but less weed-competitive cultivars need to grow for the first 15-30 days free from weed competition to express their full yield potential.



Canopy cover of hybrid and inbred cultivars 60 DAS under dry-DSR conditions at the CSISA Research Platform, Patna, India. Early ground cover by some hybrids indicates their weed competitiveness.

Table 1. Grain yield of 11 rice cultivars grown under different durations of weed competition during Kharif 2019 at Patna, Bihar.

Duration	Cultivar	Weed competition duration											Average	
		-------------------- $t\ ha^{-1}$ --------------------												
Short (115-120 d)	V1 (Hybrid)	2.42	cd[1]	(51)[3]	2.70	f	(45)	4.37	de	(11)	4.91	e	**3.60**	**e**
	V2 (Inbred)	2.44	cd	(52)	4.26	cde	(16)	4.75	cde	(6)	5.07	de	**4.13**	**d**
Medium (125-135 d)	V3 (Hybrid)	3.27	c	(46)	5.30	bc	(12)	5.63	abcd	(6)	6.02	abcd	**5.06**	**b**
	V4 (Hybrid)	2.82	cd	(54)	3.57	def	(41)	5.56	abcd	(8)	6.07	abcd	**4.50**	**cd**
	V5 (Hybrid)	5.77	a	(14)	5.87	ab	(12)	6.42	ab	(4)	6.68	ab	**6.19**	**a**
	V6 (Hybrid)	4.34	b	(38)	6.56	a	(6)	6.80	a	(3)	6.98	a	**6.17**	**a**
	V7 (Hybrid)	2.99	cd	(53)	5.08	bc	(20)	6.03	abc	(5)	6.35	abc	**5.11**	**b**
	V8 (Hybrid)	4.55	b	(17)	4.64	c	(15)	5.26	bcde	(4)	5.48	cde	**4.98**	**bc**
	V9 (Inbred)	2.14	de	(63)	4.51	cde	(23)	4.78	cde	(18)	5.86	bcde	**4.32**	**d**
	V10 (Inbred)	1.02	f	(82)	3.48	ef	(37)	4.11	e	(26)	5.53	cde	**3.60**	**e**
Long (>135 d)	V11 (Inbred)	1.20	ef	(80)	4.59	cd	(22)	4.80	cde	(19)	5.90	bcde	**4.12**	**d**
	Average	**3.00**	**D[2]**		**4.60**	**C**		**5.32**	**B**		**5.89**	**A**		
		-------------------- ANOVA (p-value) --------------------												
Weed competition (WC)		<0.001												
Cultivar (C)		<0.001												
WC*C		<0.001												

[1] *Within column means followed by the same letter are not statistically different at 5% level of probability.*

[2] *Within row means followed by the same uppercase letter are not statistically different at 5% level of probability.*

[3] *Value in parenthesis is percent yield reduction compared to the weed-free conditions.*

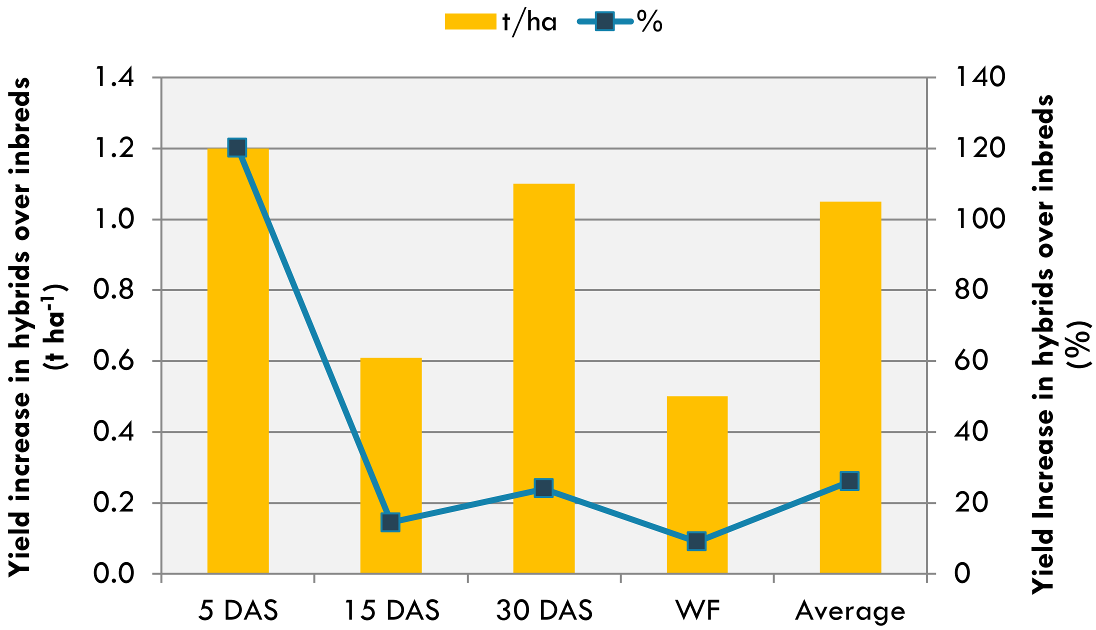


Figure 4: Yield gain with hybrid cultivars over inbred cultivars (in t ha^{-1} and %) under DSR with different durations of weed competition (starting 5, 15, and 30 days after rice sowing (DAS)) and with no weed competition (weed free) during the 2019 wet season at Patna, Bihar

Table 2. Biomass of purple rice (surrogate weed) at crop maturity when planted 5, 15, and 30 DAS during Kharif 2019 at Patna, Bihar.

Duration	Cultivar	Weed competition duration						Average	
		5 DAS		15 DAS		30 DAS			
		----------------------------g m^{-2}------------------------------							
Short (115-120 d)	V1 (Hybrid)	295	bcd	70	c	51	c	**139**	**cde**
	V2 (Inbred)	255	cde	105	bc	54	c	**138**	**cde**
Medium (125-135 d)	V3 (Hybrid)	287	bcd	88	c	59	bc	**145**	**cde**
	V4 (Hybrid)	290	bcd	79	c	65	bc	**145**	**cde**
	V5 (Hybrid)	86	e	59	c	44	c	**63**	**f**
	V6 (Hybrid)	382	abc	101	bc	69	c	**184**	**bcd**
	V7 (Hybrid)	231	cde	73	c	60	bc	**121**	**def**
	V8 (Hybrid)	180	de	54	c	45	c	**93**	**f**
	V9 (Inbred)	530	a	119	bc	75	bc	**241**	**ab**
	V10 (Inbred)	454	ab	232	a	128	a	**271**	**a**
Long (>135 d)	V11 (Inbred)	330	bcd	188	ab	94	ab	**204**	**abc**
	Average	**302**	**A**	**106**	**B**	**68**	**C**		

[1] *Within column means followed by the same letter are not statistically different at 5% probability level*
[2] *Within row means followed by the same uppercase letter are not statistically different at 5% probability level*

Experiment 3: PERFORMANCE OF BASMATI RICE VARIETIES UNDER DRY-DSR AND PUDDLED TRANSPLANTED RICE (PTR) IN PUNJAB, INDIA

This experiment was conducted in collaboration with Punjab Agricultural University (PAU), Ludhiana, Punjab to compare the performance of the most commonly available basmati rice varieties in Punjab for yields under both transplanted and dry-DSR conditions.

Collaborating scientists: Dr. Buta Singh Dhillon, PAU

Location of study: This study was conducted at Research Farm of PAU, Ludhiana

Treatments

Factor 1: Establishment methods (EM)

- Dry-seeded rice (Dry-DSR)
- Puddled transplanted rice (PTR)

Factor 2: Basmati rice varieties (6)

- Pusa Basmati 1121
- Pusa Basmati 1637
- Pusa Basmati 1718
- Punjab Basmati 4
- Punjab Basmati 5
- RYT 3677

Experimental design: Factorial randomized complete block design with three replications

Method:
DSR was sown on June 15, 2019, using seed and fertilizer drills at a seed rate of 20 kg ha^{-1} in lines with 20-cm row spacing. Immediately after sowing, irrigation was applied to facilitate good crop establishment. On the day of the DSR sowing, a rice nursery was established for PTR treatment and 30-day-old seedlings were transplanted in the PTR plots. All the plots were kept weed-free using herbicides and hand weeding. In DSR plots, a pre-emergence herbicide (pendimethalin at 750 g ai ha^{-1}) was applied, followed by a post-emergence herbicide (bispyribac-sodium at 20 g ai ha^{-1}); these applications were complemented with needs-based one-hand weeding. In the PTR plots, pretilachlor 750 g ai ha^{-1} was applied as a pre-emergence herbicide after transplanting, followed by one-hand weeding.

Results: Both variety and crop establishment method significantly influenced rice yields (Fig. 5; ANOVA table). On average, irrespective of variety, rice yield was 17% higher under PTR than DSR. Among rice varieties, RYT-3677 produced the highest yield (4.9 to 5.2 t ha^{-1}) followed by Pusa Basmati-1718, Pusa Basmati-1121 and Punjab 5 (3.7 to 4.2 t ha^{-1}). The lowest yield was produced in Punjab Basmati-4, and Pusa Basmati-1637 (2.2 to 4.2 t ha^{-1}). RYT-3677, Pusa-1121, Pusa-1718, and Punjab Basmati-5 produced similar yields under DSR and PTR, suggesting that these basmati rice varieties are suitable under both DSR and PTR. In contrast, Punjab Basmati-4 and

Pusa Basmati-1637 were not found suitable for DSR conditions, as evident from the 47% and 18% reductions in rice yield in DSR compared to PTR.

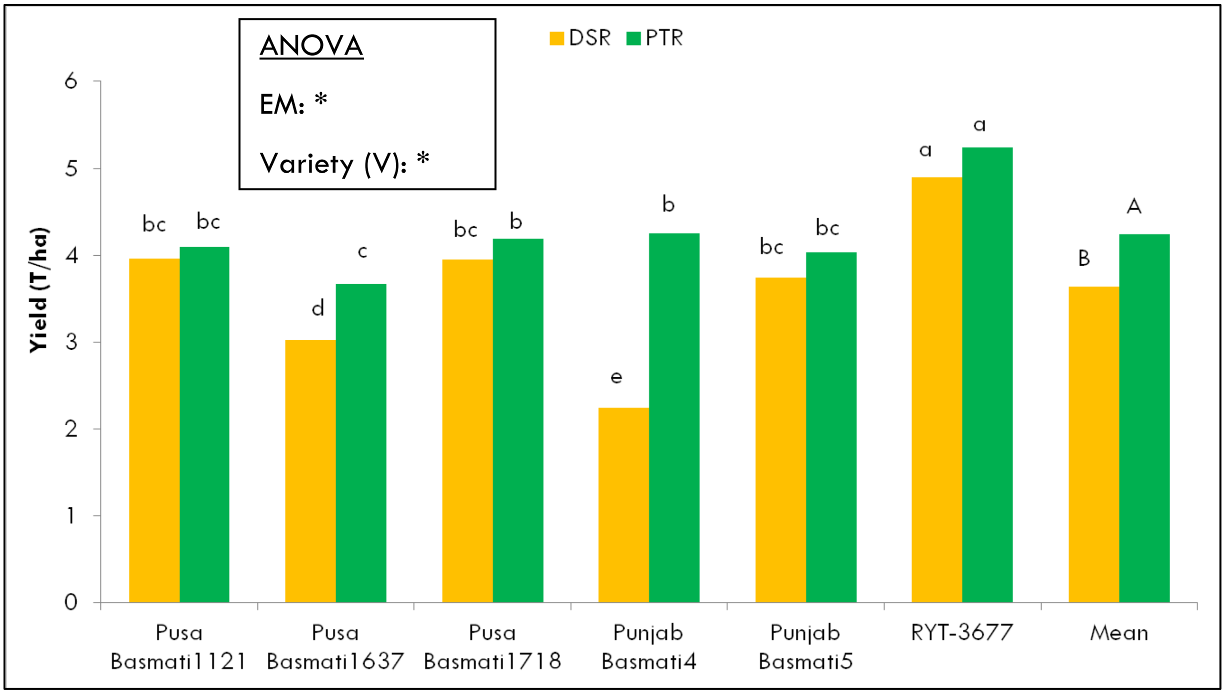


Figure 5. Rice grain yield of basmati rice varieties under dry-seeded rice (DSR) and puddled transplanted rice (PTR) conditions during the 2019 wet season at Ludhiana, Punjab.

*Different lowercase letters indicate significant difference among varieties x establishment method.

** Different uppercase letters indicate significant difference in crop establishment method (DSR vs PTR).

1.2. Evaluating Drip Irrigation for Direct-Seeded Rice (DSR)-Based Cropping Systems in Eastern India to Address Its Benefits

Rationale: Water is becoming scarce and expensive in Asia. Rice cultivation is a major source of fresh water consumption in agriculture accounting for ~50% of total irrigation water use in Asia. On average, the water application in the conventional practice of PTR is about 2500 liters to produce 1 kg of rough rice. Despite the similarities in the water productivity of rice to other C3 cereals based on evapotranspiration (ET), higher irrigation water application in rice is attributed to water requirements for puddling and losses associated with continuous flooding, such as seepage and deep percolation losses to groundwater. The grim future scenario of water availability for the agriculture sector and the highly water-inefficient current practices in rice production warrant exploration of alternative rice production methods and irrigation water management practices that inherently require less irrigation water and/or use irrigation water more efficiently. Dry-DSR is one such alternative rice establishment method that can save irrigation water compared to PTR. In addition, micro-irrigation practices such as drip irrigation (surface or sub-surface), also offer opportunities to further reduce irrigation water use in dry-DSR by reducing evaporation, percolation, and seepage losses. These practices will also reduce methane emissions from paddy fields. In addition, drip irrigation also facilitates fertigation and would therefore enhance nutrient-use efficiencies.

A field study was conducted to evaluate the performance of drip irrigation in rice-based systems and quantify the benefits and trade-offs (if any) of micro-irrigation at the systems level. The overall aim is to provide the integrated knowledge required by researchers, crop advisors, irrigation managers, and decision-makers to assess and better manage future rice-based production systems with drip irrigation. The specific objectives of this study were as follows:

1. To estimate the irrigation water savings with drip irrigation compared to the flood irrigation in rice-wheat and rice-maize systems

2. To evaluate the impact of drip and fertigation on yield, water productivity, and resource-use efficiencies (water and nutrient) at the crop and cropping systems level in rice-wheat and rice-maize systems

Location: This study was conducted at the DSR Field Laboratory established at IRRI South Asia Regional Centre (ISARC) in Varanasi, Uttar Pradesh (25.303952 N Latitude, 82.946873 E longitude and 70 m above mean sea level).

Treatment details:

T1. Rice (DSR) fb ZT wheat with surface drip irrigation (S-DSR), laterals placed at 60-cm spacing [DSR fb ZTW with surface drip]

T2. Rice (DSR) fb ZT wheat with sub-surface drip irrigation (SS-DSR), laterals placed at 60-cm spacing [DSR fb ZTW with sub-surface drip]

T3. Rice (DSR) fb ZT maize with surface drip irrigation, laterals placed at 60-cm spacing [DSR fb ZTM with surface drip]

T4. Rice (DSR) fb ZT maize with sub-surface drip irrigation, laterals placed at 60-cm spacing [DSR fb ZTM with sub-surface drip]

T5. Rice (DSR) fb ZT wheat with irrigation applied with flood irrigation method at 10 kPa for rice (T-DSR) and at critical growth stages for wheat [DSR fb ZTW with conventional irrigation method]

T6. Rice (DSR) fb ZT maize with irrigation applied with flood irrigation method at 10 kPa for rice and at 35 kPa for maize [DSR fb ZTM with conventional irrigation method]

T7. Puddled transplanted rice fb ZT wheat [PTR fb ZTW with conventional irrigation method]

T8. Puddled transplanted rice fb ZT maize [PTR fb ZTW with conventional irrigation method]

Experimental design: Randomized complete block design (RCBD) with three replications

Plot size: 14.0 m x 4.5 m

Method:

Rice variety DRR Dhan 44 was used in this experiment. In DSR plots, rice was sown on July 1, 2019, with a seed rate of 25 kg ha^{-1} using a multi-crop planter at 20-cm row-to-row spacing. In DSR, seeding was performed in *vattar* conditions (residual moisture). For transplanted rice, the seed was soaked for raising nursery on the day of direct seeding. Twenty-five-day-old seedlings were used for transplanting PTR plots. Fertilizer management and weed management were similar to the varietal experiment (under section 1.1, Experiment 1). For water management, irrigation was applied as per the respective treatments. In drip treatments, irrigation was applied based on daily pan evaporation. In DSR with the conventional irrigation method (flood irrigation), rice was irrigated as needed for the first three weeks to ensure good crop establishment and subsequent irrigation was applied at 10 kPa soil matric potential (SMP) at 15-cm soil depth. Tensiometers were installed to monitor SMP. In PTR, in the first 2 weeks, flooding was maintained, then irrigation was applied using the same criteria as in DSR at 10 kPa SMP at 15-cm depth. When plots reached 10 kPa SMP, the plots were irrigated to 5-cm standing water. For each irrigation, the water volume was recorded. Under both surface- and subsurface-drip plots, the 2nd and 3rd splits of urea were applied through drip lines using Venturi. Except for the water management treatments, best management practices were followed throughout the cropping season. As a preventive measure for stem borer, cartap-hydrochloride, a systemic insecticide was applied @ 10 kg ha^{-1} at 42 DAS. For protection from fungal attack, a systemic fungicide, Nativo (Tebuconazole and Trifloxystrobin), was applied at 78 DAS (pre-flowering stage). Data on plant height (cm), number of tillers m^{-2}, irrigation water volume, yield and yield attributes, and grain quality were recorded.

Results:

Results showed that rice yields were statistically similar among all treatments (p-value= NS, Table 3). In contrast, irrigation water was influenced by the treatments (p-value= <0.0001). In DSR with drip irrigation systems (surface or sub-surface irrigation), irrigation application was 12 cm ha^{-1} as compared to 83 cm ha^{-1} in DSR and 89 cm ha-1 in PTR with conventional irrigation methods applied at a soil tension of 10 kPa at 15-cm soil depth. An 85 to 87% irrigation water savings was achieved using DSR with the drip irrigation method as compared to PTR and DSR without drip irrigation.

Table 3. Rice grain yield and irrigation water application in different rice establishment and irrigation methods during the 2019 wet season at ISARC, Varanasi, India

Trt ID	Establishment method/ cropping system	Irrigation method	Yield (t ha^{-1})	Irrigation water (cm/ha)[2]
T1	DSR fb ZTW	Surface drip	4.6	12 c[1]
T2	DSR fb ZTW	Sub-surface drip	4.8	12 c
T3	DSR fb ZTM	Surface drip	4.5	12 c
T4	DSR fb ZTM	Sub-surface drip	4.9	12 c
T5	DSR fb ZTW	Conventional	4.7	83 b
T6	DSR fb ZTM	Conventional	4.7	83 b
T7	PTR fb ZTW	Conventional	5.0	89 a
T8	PTR fb ZTM	Conventional	5.1	89 a
ANOVA (p-value)			*NS*	*<0.001*
CONTRAST ANALYSIS (p-value)				
Surface drip (T1& T3) vs sub-surface drip (T2 & T4)			0.048	NS
Drip DSR (T1, T2, T3, T4) vs conventional DSR (T5 &T6)			NS	<0.0001
DSR (T1-T6) vs PTR (T7 & T8)			0.0033	<0.0001

[1] Within column means followed by the same letter are not statistically different at 5% level of probability using Tukey's HSD test.

[2] This is only irrigation water. However, during the cropping season 1314 mm of rainfall also occurred.

Based on contrast analysis, the results showed that the DSR yield was 6% higher under sub-surface irrigation method (T2 & T4) than under surface irrigation (T1 and T3) with the same irrigation water application (Table 3). This may be due to higher nutrient and water efficiencies in the sub-surface drip method than in the surface drip system. Rice yield was similar in DSR with a drip irrigation system (T1-T4) and DSR with a normal flood irrigation method (T5-T6), but with 85% less irrigation water. When comparing all DSR treatments (T1-T6) with PTR treatments (T7-T8), rice yield was 6% higher in PTR than in DSR treatments but with much higher irrigation water use. This slight difference in yield between DSR and PTR could be attributed to the difference in lodging; >80% lodging was observed in DSR plots whereas there was no lodging in PTR plots. These results further suggest the importance of higher lodging resistance in DSR.

Field view of drip irrigation experiment at ISARC, Varanasi, India.

1.3. Effect of Pre-Sowing Seed Treatments/Priming on Performance of Dry-Seeded Rice

Rapid, uniform and good crop establishment are crucial for attaining full yield potential and suppressing weeds in DSR. Pre-sowing seed priming/treatments can facilitate rapid and uniform seedling establishment, and early growth in DSR. Seed priming has been shown to positively affect emergence, yield, and grain quality in various crops, including rice. In India, in dry-DSR, good crop establishment is limited by the sub-surface soil drying associated with high temperatures. It is therefore hypothesized that pre-sowing seed priming/treatment will improve crop establishment of DSR crops, which will result in higher grain yields.

Collaborating scientists: Dr. Buta Singh Dhillon, PAU

Location of study: This study was conducted at Research Farm of PAU, Ludhiana, India.

Treatments

Factor 1: Seed priming/treatment (11):

1. Control (dry seed)
2. Hydro priming 12-hr
3. Hydro priming 24-hr
4. 25-ppm GA312-hr
5. 25-ppm GA3 24-hr
6. 50-ppm GA3 12-hr
7. 50-ppm GA3 24-hr
8. 1% KNO_3 12-hr
9. 1% KNO_3 24-hr
10. 2% KNO_3 12-hr
11. 2% KNO_3 24-hr

Note: GA = Gibberellic acid and KNO_3 = Potassium nitrate

Factor 2: Sowing methods (SM) (2)

SM1: Sowing in dry soil conditions fb irrigation

SM2: Sowing in moist/*vattar* soil conditions, known as *soil mulching* (pre-sowing irrigation fb sowing in moist conditions under field capacity)

Experimental design: Randomized complete block design with three replications

Methods:

Rice variety PR 126 was used in this trial. The crop was sown on June 6, 2019. In sowing method 1 (SM1) (sowing in dry fb irrigation), irrigation was applied on the day of sowing to facilitate good establishment. In contrast, in SM2 (*soil mulching*/seeding in *vattar*), the first post-sowing irrigation was applied 21 days after rice sowing. Eleven seed priming treatments were evaluated under both establishment methods. Other crop management practices were the same in all plots and were as per PAU recommendations.

Results:

The results showed that seed priming prior to sowing influenced the rice yield under both dry-DSR sowing methods (Fig. 6). Hydro-priming of seed for 12 to 24 hours did not increase the yield significantly compared to dry seed (non-primed). However, seed priming with 25 to 50 ppm gibberellic acid or 2% potassium nitrate for 12 to 24 hours resulted in an 8-13% increase in yield in SM2 (*vattar* DSR) and a 6-10% increase in SM1 (dry seeding). This improvement in productivity could be attributed to improvement in the emergence and growth of seedlings, leading to a higher vigor index of seedling (data not included).

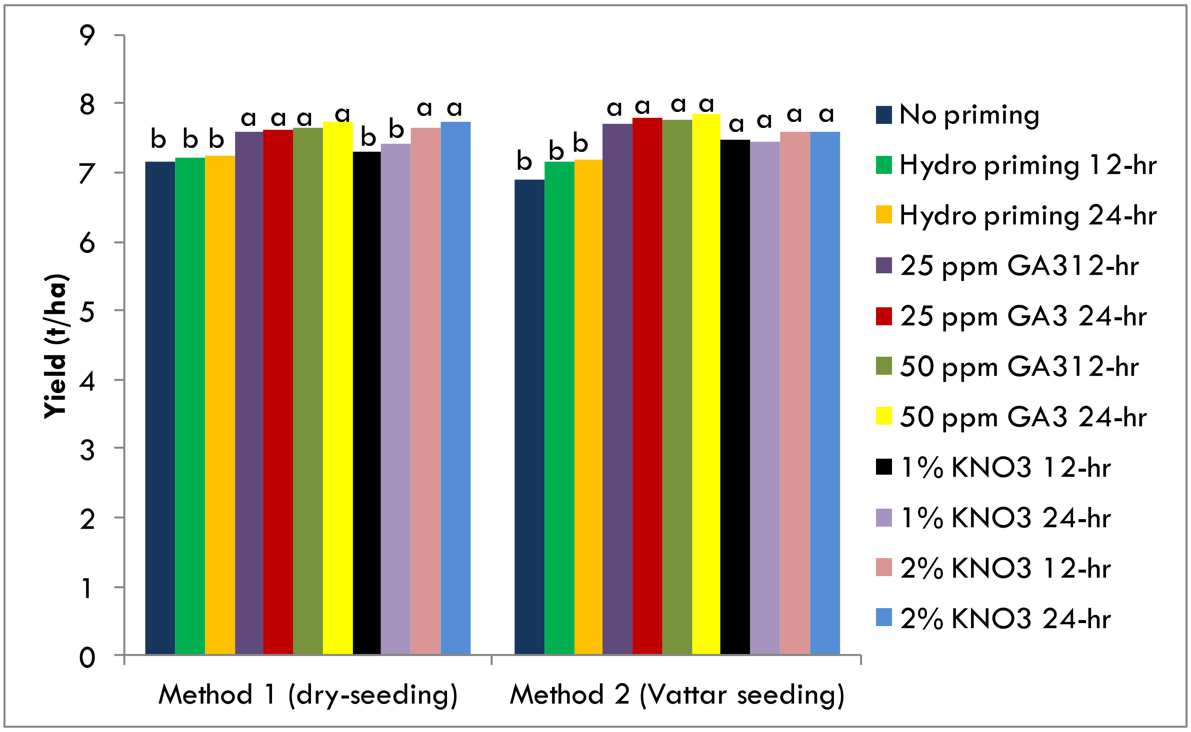


Figure 6. Rice yields of dry-DSR establishment methods with different seed priming treatments during the 2019 wet season at PAU, Ludhiana.

*Within each seeding method, different letters indicate significant difference in treatments using an LSD test at 5% level.

1.4. Optimizing Time of First Irrigation for Direct-Seeded Rice Sown in Moist Conditions (Known as *'Soil Mulching'* or *'Vattar Sowing'*)

One of the major limitations of DSR is the risk of poor and uneven crop establishment if fields are inundated by monsoon rains during crop emergence/early establishment; this can lead to crop failure, reduced weed competitiveness, or lower yield. One of the approaches used to reduce this risk is reliably establishing the rice crop early before the chance of heavy monsoon rain increases. However, early sowing can lead to high irrigation requirement until the monsoon rain commences because of prevailing high evaporation conditions (i.e., a dry period with high temperatures) unless soil moisture conservation practices such as soil mulching are utilized.

DSR can be established either by (1) sowing in dry soil followed by irrigation (dry-DSR) or (2) sowing in moist soil (*vattar* DSR), aka soil mulching. Soil mulching is a simple management adjustment that uses pre-sowing irrigation followed by shallow tillage (to break soil capillaries and creates soil mulch) before rice seeding to attain better weed control and limit evaporation losses. This reduces the early irrigation requirement and therefore facilitates early sowing of DSR (2 to 3 weeks before the onset of monsoon) at a time when rice can be established to avoid risk of stand mortality due to inundation by the monsoon rains. In contrast, seeding in dry soil fb irrigation would require frequent irrigation (once every 4-5 days) if the rice is sown early because of high evaporation losses through soil capillaries in late May/early June when the temperature is very high (~ 40° C). Although irrigation immediately after sowing facilitates good crop emergence, it also favors establishment of weeds along with the rice. In contrast, when soil mulching is used, it is hypothesized that the top 2 cm of the soil – the layer in which most of the weeds establish – dries quickly, and weed establishment is reduced; moisture below 2 cm is conserved, enabling good rice establishment and reducing the need for early irrigation. Delaying first irrigation will reduce weed problems in addition to reducing the irrigation requirement. However, there is limited information available on when the first irrigation should be performed so that it does not affect rice yield. There is a need to optimize the timing of first irrigation with the *soil-mulching/vattar* sowing method in DSR.

This study was conducted with the following objectives:

1. Optimizing the time of first irrigation and assessing the impact of time of first irrigation on rice growth and yield
2. Assessing the effect of the timing of first irrigation on weed suppression
3. Assessing the impact of time of first irrigation on irrigation water savings

Collaborating scientists: Dr. Buta Singh Dhillon, PAU

Location of study: This study was conducted at Research Farm of PAU, Ludhiana.

Treatments: Time of first irrigation

- 0 DAS
- 14 DAS
- 21 DAS

Methods:

Rice variety PR 126 was used in this trial. The crop was sown on June 6, 2019. Pre-sowing irrigation was applied, and when the field came into field capacity/*vattar* conditions, it was tilled, and leveled. The rice was then sown with a seed-cum-fertilizer drill with a light wooden plank attached behind the drill to achieve good seed-to-soil contact. First irrigation was applied as per treatment at 0 DAS, 14 DAS, and 21 DAS. After the first irrigation, follow-up irrigations were applied using the same criteria in all the plots. The data on yield and yield attributes, plant growth, irrigation water, weed density, and biomass at 35 DAS were recorded. Other crop management practices were used as per PAU recommendations.

Results:

Results show that in DSR with soil mulching, the first irrigation can be delayed 21 days by conserving soil moisture (a soil mulch effect) without adversely affecting rice yield (Fig. 7). The rice yield was similar when first irrigation was applied at 0, 14 and 21 days after sowing (Fig. 7A). Soil mulching also reduced weed pressure when irrigation was delayed to 14 or 21 days after sowing (~71-74% lower weed density and 62% less weed biomass) as compared to the treatments in which irrigation was applied immediately after sowing (Fig. 7B). However, delaying the first irrigation until 14 and 21 days after sowing resulted in irrigation water savings of 6% and 12%, respectively, as compared to irrigation applied immediately after sowing (Fig. 7C). These results suggest that soil mulching is a viable risk-reducing agronomic practice that reduces weed pressure and saves irrigation water without impacting rice yields.

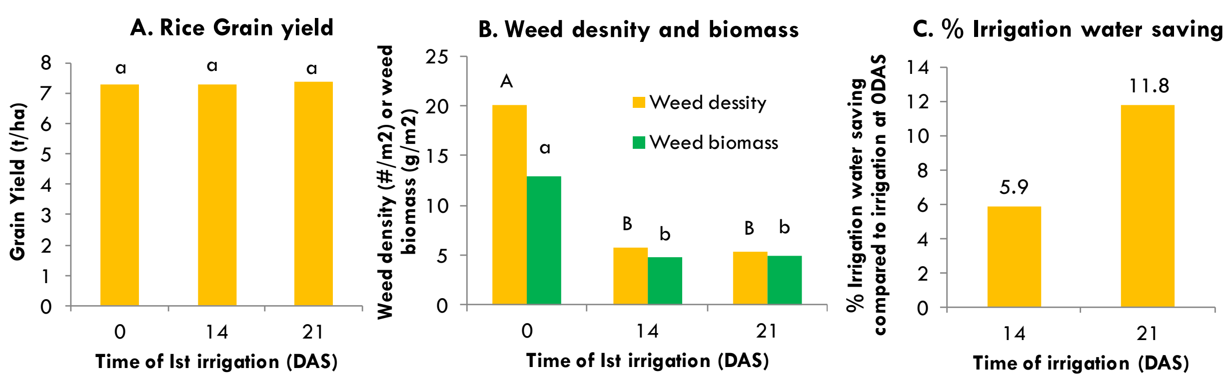


Figure 7. Effect of first irrigation timing on the (A) grain yield of rice and (B) weed density and weed biomass at 35 DAS, and (C) irrigation water saving in DSR sown under moist soil/*vattar* conditions during the 2019 wet season at PAU, Ludhiana. *Different lowercase letters indicate significant difference in treatments using LSD test at the 5% level. For weed data, different uppercase letters indicate significant difference in treatments for weed density and different lowercase letters indicate difference in treatments for weed biomass.

1.5. Weed Management in Direct-Seeded Rice

Weeds are a major factor limiting attainment of optimal grain yields in DSR and its wide-scale adoption of this method. Weed management is more challenging in DSR than in PTR because the newly emerging rice seedlings are less competitive to simultaneously emerging weed seedlings than transplanted seedlings, and using early flooding to suppress initial flushes of weeds is not an option in DSR. Changes in water, tillage, and weed management practices in DSR can lead to a variety of weed-related issues, including (1) shifts in weed flora toward difficult-to-control weeds; (2) evolution of weedy rice, which is highly competitive and for which there are limited control options; and (3) increased dependence on herbicides for weed control, which leads to risks of evolving herbicide resistance in weed species. To manage weeds effectively in DSR and to delay or manage the risk of evolution of herbicide resistance in weeds, it is important to test herbicides with different modes of action or tank-mix combinations.

To develop strategies to avoid herbicide resistance, on-station research trials were conducted with NARES partners, including the National Rice Research Institute (NRRI), Cuttack and Visva-Bharti University in Santiniketan, West Bengal. New herbicide molecules with different modes of action (MOAs) were evaluated and compared with current standard check/s. Details of these experiments are given below.

Experiment 1: PERFORMANCE EVALUATION OF NEW PRE-MIX COMBINATIONS OF PENOXSULAM + CYHALOFOP-BUTYL (VIVAYA 6 OD) AND FLORPYRAUXIFEN-BENZYL + CYAHALOFOP-BUTYL (NOVLECT 12EC) UNDER DRY-SEEDED RICE CONDITIONS

Collaborating scientist: Dr. B. Duary, Visva-Bharti University (VBU), West Bengal, India.

Location of the Experiment: This experiment was conducted at the Agricultural Farm of the Institute of Agriculture, Visva-Bharati University (VBU), West Bengal, India. The experimental plot is located in the sub-humid lateritic belt of West Bengal at 23^0 39.331′ N Latitude, 87^0 41.227′ E longitude and 54 m above mean sea level (msl).

Treatment: A total of 9 herbicide treatments were evaluated; details of these treatments are given in Table 4.

Table 4. Description of herbicide treatment with their doses and application time

Tr. #	Treatment	Dose (g ai ha^{-1})	Formulated dose (ml ha^{-1})	Application Time
T1	Pre-mix penoxsulam + cyhalofop-butyl (Vivaya 6 % OD)	150	2500	4-leaf stage of weeds (21 DAS)
T2	Pre-mix penoxsulam + cyhalofop-butyl (Vivaya 6 % OD)	180	3000	4-leaf stage of weeds (21 DAS)
T3	Fenoxaprop-p-ethyl (Ricestar 9 EC) + ethoxysulfuron (Sunrice 15 WDG)	90 + 15	1000 + 100	4-leaf stage of weeds (21 DAS)
T4	Pre-mix Florpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12 EC)	150	1250	4-leaf stage of weeds (21 DAS)
T5	Pre-mix Florpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12 EC)	180	1500	4-leaf stage of weeds (21 DAS)
T6	Novlect 12 % EC + fenoxaprop-p-ethyl (Ricestar 9 EC)	150 + 60	1500 + 660	4-leaf stage of weeds (21 DAS)
T7	Pendimethalin PE (Stomp 30 EC) as PRE fb bispyribac sodium (Nominee Gold 10 SC)	1000 + 25	3300 + 250	PRE 1DAS fb POST – 4-leaf stage of weeds (21 DAS)
T8	Untreated control			
T9	Weed-free check			

Rice variety: MTU 1010

Date of sowing: June 25, 2019

Experimental Design: RCBD

Plot size: 7.0 m x 4.0 m

Replication: Three

Methodology:

Rice variety *MTU 1010* was sown on June 25, 2019, with a seed rate of 60 kg ha^{-1} at 20-cm row-to-row spacing. Fertilizer N, P_2O_5 and K_2O @ 80, 40 and 40 kg ha^{-1} were applied in the experimental plot through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. Nitrogen was applied in 3 splits (1/3 N as basal and the remaining 2/3 in two equal split doses at active tillering and panicle initiation), and a full dose of phosphorus and potash were applied as basal during final land preparation. In addition, zinc as ZnSO4.7H2O @ 25 kg ha^{-1} was also applied as basal. Application of 1% urea + 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ foliar spray was performed twice at 30 and 45 DAS as a booster spray. The observations on various growth attributes of rice, such as plant height and number of tillers m^{-2}, were recorded from the earmarked area using non-destructive sampling. Weed flora composition, species- and category-wise weed population, and biomass of weeds were recorded at different growth stages. The yield components, including number of panicles m^{-2}, grains per panicle, 1000-grain weight (test weight) and yield of rice, were also recorded.

Results:

The predominant weeds observed at the study site were as follows: *Digitaria sanguinalis* and *Echinochloa colona* among the grasses; *Ludwigia parviflora* among the broadleaved weeds; and *Cyperus iria* among the sedges. *Digitaria* constituted the major share of the total weed flora. Post-emergence (POST) application of pre-mix penoxsulam + cyhalofop (Vivaya) both at 150 and 180 g ai ha^{-1} doses did not exhibit satisfactory control of *D. sanguinalis* when observations were recorded at 45 DAS (Table 5). A similar trend was observed with respect to the biomass of *D. sanguinalis* (Table 6) for which the weed-control efficiency of Vivaya at 45 DAS was only 20%. As *Digitaria* constituted a major share of the grassy weeds, Vivaya did not exhibit good control of total grasses in the present experiment. It was also weak on the control of *L. parviflora* at the lower dose but at the higher dose, it provided 70% control. However, this herbicide exhibited satisfactory control of *E. colona* (74% WCE at 45 DAS with higher dose) and 100% control of C. *iria* with both doses (Table 6).

Pre-mix applications of florpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12% EC) (T4 & T5) were not very effective against *D. sanguinalis* and other weeds *like Ludwigia parviflora*. However, this pre-mix was found to be highly effective against *Digitaria* when tank mixed with fenoxaprop (Ricestar) (T6) (Table 5 & 6). The tank mix combination of fenoxaprop (Ricestar) and ethoxysulfuron (Sunrice) (T6) provided about 90% control of *Digitaria* and exhibited good weed control of complex weed flora (Table 6). Tank mix application of Novlect and Ricestar (T6) was found effective against most of weed species, registering 85% weed-control efficiency (WCE) for grasses and 100% WCE for broadleaved weeds, with about 82% WCE of all of the weed species tested (Table 6). Novlect + Ricestar (150 + 60) showed a significantly lower density and biomass of grassy and broadleaved weeds at 45 DAS and was found to be on par with fenoxaprop-p-ethyl (Ricestar 9 EC) + ethoxysulfuron (Sunrice 15 WDG) (90 + 15) (Table 5).

Among the tested herbicides, the tank mix of Novlect + Ricestar (T6) produced the highest grain yield. This tank mix was similar to the weed-free check and standard check of pendimethaline fb bispyribac followed by fenoxaprop + ethoxysulfuron, which was similar to pendimethalin fb bispyribac but 16-20% lower than weed-free and Novlect + Ricestar treatments (Fig. 8). Vivaya (T1 and T2) and Novlect increased the yield from 423 kg ha-1 (weed check) to >2000 kg ha-1 but compared to weed-free check, it was 27-50% lower, mainly because it exhibited poor control over the most dominant weed, *D. sanguinalis*.

Table 5. Weed density (No. m^2) under different weed management treatments at 45 DAS

Trt ID	Weed density (No. m^2) at 45 DAS						
	DIGSA	*ECHCO*	**Total grass**	*LUDPA*	**Total broadleaved**	**Sedge**	**Total weed**
T1	9.1 (83)	3.3 (11)	9.7 (94)	2.7 (7)	2.7 (7)	0.7 (0)	10.1 (101)
T2	9.0 (81)	3.0 (9)	9.5 (89)	2.4 (5)	2.4 (5)	0.7 (0)	9.7 (95)
T3	3.4 (11)	3.5 (12)	4.9 (23)	2.1 (4)	2.1 (4)	0.7 (0)	5.2 (27)
T4	9.3 (85)	3.2 (10)	9.8 (95)	0.7 (0)	0.7 (0)	0.7 (0)	9.8 (95)
T5	9.3 (85)	2.7 (7)	9.6 (92)	0.7 (0)	0.7 (0)	0.7 (0)	9.6 (92)
T6	3.9 (15)	3.6 (13)	5.3 (27)	0.7 (0))	0.7 (0)	3.3 (12)	6.3 (39)
T7	5.5 (30)	5.0 (24)	7.4 (54)	0.7 (0)	0.7 (0)	0.7 (0)	7.4 (54)
T8	9.3 (86)	5.3 (27)	10.7 (113)	2.6 (6)	2.6 (6)	0.7 (0)	11 (120)
T9	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)
LSD (P=0.05)	0.94	0.51	0.87	0.29	0.29	0.91	0.91
CV (%)	8.49	8.96	6.91	11.44	11.44	15.02	7.05

* Figures in parenthesis are original value and data were square root transformed.

DIGSA = Digitaria sanguinalis; ECHCO = *Echinochloa colona; LUDPA= Ludwigia parviflora*

Table 6. Weed biomass (g m^{-2}) under different weed management treatments at 45 DAS

Trt ID	Weed biomass (g m^{-2}) at 45 DAS						
	DIGSA	*ECHCO*	**Total grass**	*LUDPA*	**Total broadleaved**	**Sedge**	**Total weed**
T1	15.5 (239)	4.5 (20)	16.1 (259)	1.7 (3)	1.7 (3)	0.7 (0)	16.2 (262)
T2	13.9 (193)	2.9 (8)	14.2 (201)	1.3 (1)	1.3 (1)	0.7 (0)	14.2 (202)
T3	5.0 (24)	4.5 (20)	6.7 (45)	1.2 (1)	1.2 (1)	0.7 (0)	6.8 (46)
T4	15.2 (232)	4.2 (17)	15.7 (249)	0.7 (0)	0.7 (0)	0.7 (0)	15.7 (249)
T5	14.0 (199)	3.6 (13)	14.5 (212)	0.7 (0)	0.7 (0)	0.7 (0)	14.5 (212)
T6	4.9 (24)	3.9 (15)	6.2 (38)	0.7 (0)	0.7 (0)	2.6 (9)	6.9 (48)
T7	6.6 (43)	5.0 (24)	8.3 (68)	0.7 (0)	0.7 (0)	0.7 (0)	8.3 (68)
T8	15.5 (242)	5.5 (30)	16.5 (271)	2.2 (4)	2.2 (4)	0.7 (0)	16.6 (276)
T9	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)
$LSD_{0.05}$	2.04	0.76	1.94	0.24	0.24	1.18	2.08
CV (%)	12.07	11.84	10.56	12.83	12.83	14.57	11.24

* Figures in parenthesis are original value and data were square root transformed.

DIGSA = Digitaria sanguinalis; ECHCO = *Echinochloa colona; LUDPA= Ludwigia parviflora*

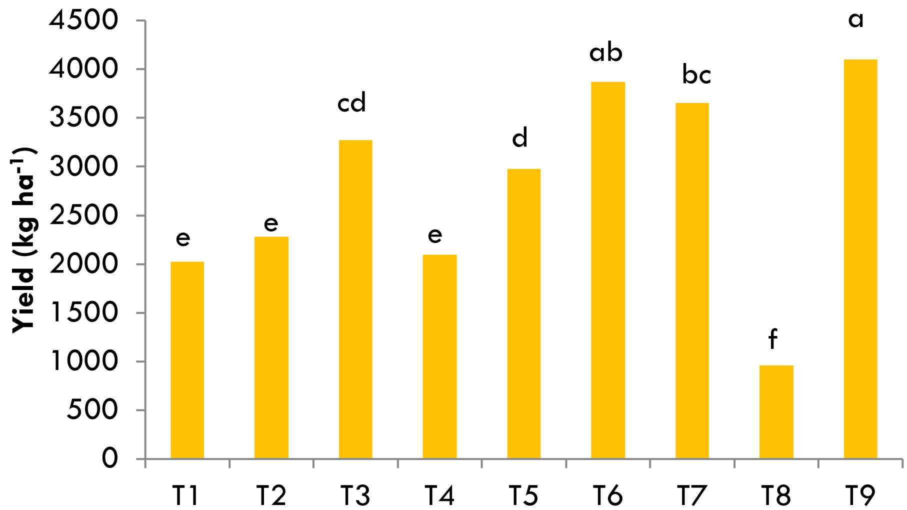


Figure 8. Rice yield under different weed management treatments during the 2019 wet season.

Experiment 2: HERBICIDE-BASED WEED MANAGEMENT IN DSR USING HERBICIDES WITH DIFFERENT MODES OF ACTION

Collaborating scientist: Dr. B. Duary, Visva-Bharti University (VBU), Sriniketan, West Bengal

Location of the Experiment: same as Experiment 1 (VBU), Sriniketan, West Bengal, India).

Treatment: A total of 9 herbicide treatments were evaluated; details are given below in Table 7.

Table 7. Description of herbicide treatments with their doses and application times

Tr. No	Treatment	g ai ha^{-1}	Application Time
T1	Pendimethalin (STOMP) as PRE fb bispyribac -sodium (Nominee Gold) as POST	1000 + 25	PRE at 1 DAS; POST at 2- 4 leaf stage of weeds (18 DAS)
T2	Oxadiargyl (Topstar) as PRE fb bispyribac-sodium as POST	90 + 25	PRE at 1 DAS; POST at 2- 4 leaf stage of weeds (18 DAS)
T3	Premix Florpyrauxifen-benzyl + cyhalofop (Novlect) as early POST	150	1- to 3-leaf stage of weeds (15 DAS)
T4	Ethoxysulfuron + Fenoxaprop (Ricestar) as early POST	15 + 90	1- to 3-leaf stage of weeds (18 DAS)
T5	Fenoxaprop-p-ethyl + metsulfuron + chlorimuron (Almix) as early POST	90 + 4	1- to 3-leaf stage of weeds (18 DAS)
T6	Fenoxaprop (Ricestar) + bispyribac sodium as early POST	90 + 25	1- to 3-leaf stage of weeds (18 DAS)
T7	Penoxsulam + Fenoxaprop (Ricestar) as early POST	24 + 90	1- to 3-leaf stage of weeds (18 DAS)
T8	Untreated control		
T9	Weed free check		

Rice variety: MTU 1010

Experimental Design: RCBD

Replication: Three

Date of sowing: June 26, 2019

Plot size: 7.0 m x 4.0 m

Methodology: same as in Experiment 1

Results:

Digitaria sanguinalis, *Echinochloa colona,* and *Cyperus iria* were major weed species recorded at 45 DAS. *Hedyotis corymbosa* was observed in the plots treated with ethoxysulfuron + fenoxaprop-p ethyl. Pendimethalin fb bispyribac sodium (W1) and oxadiargyl fb bispyribac sodium (W2) registered lower density and biomass of *Digitaria*, *Echinochloa*, *and Cyperus* species, resulting in the lowest total weed biomass followed by ethoxysulfuron + fenoxaprop-p-ethyl and penoxsulam + fenoxaprop-p-ethyl as early POST (Table 8). More than 90% reduction of total weed biomass was observed with the herbicide pendimethalin fb bispyribac sodium and oxadiargyl PE fb bispyribac sodium followed by Penoxsulam + fenoxaprop-p-ethyl (W7) (87%). Ethoxysulfuron + fenoxaprop-p-ethyl reduced weed biomass of *Digitaria* approximately 92%. Penoxsulam + fenoxaprop-p-ethyl as early POST also exhibited a reduction of more than 80% in *Digitaria* biomass. Performance of the different herbicide treatments can be seen in the inset below.

Table 8. Weed biomass under different weed control treatments at 45 DAS[1]

Treatment	Weed biomass (g m^{-2}) at 45 DAS						
	DIGSA	*ECHCO*	Total grass	*HEDCO*	Total broadleaved	Sedge	Total weed
T1	17 d	0 c	17 f	0 b	0 b	0 b	17 f
T2	21 d	0 c	21 f	0 b	0 b	0 b	21 f
T3	82 bc	0 c	82 d	0 b	0 b	0 b	82 d
T4	21 d	0 c	21 f	87 a	87 a	0 b	109 cd
T5	107 b	48 b	154 b	0 b	0 b	0 b	154 b
T6	115 b	0 c	115 c	0 b	0 b	0 b	115 c
T7	54 c	0 c	54 e	0 b	0 b	0 b	54 e
T8	275 a	129 a	404 a	0 b	0 b	8 a	411 a
T9	0 e	0 c	0 g	0 b	0 b	0 b	0 g

[1]DIGSA = Digitaria sanguinalis; ECHCO = *Echinochloa colona;* HEDCO=*Hedyotis corymbosa*

Data were square root transformed. The data presented in the table is actual data.

The highest grain yields were recorded in treatments with PRE fb POST treatments (T1 and T2), which did not differ, and T1, which produced a yield similar to weed-free check (Fig. 9). Among total post-emergence treatments (T3-T7) and T4 (fenoxaprop + ethoxysulfuorn) produced the highest yields, which was not different from T2 but were 17% lower than T1 and 26% lower weed-free plots. This was followed by T7 (penoxsulam + fenoxaprop), which produced a yield similar to T4 (fenoxaprop + ethoxysulfuron), suggesting acceptable compatibility of the mixture; however, its efficacy was 15-20% lower than PRE fb POST treatments (T1 and T2) and 28% lower than the weed-free treatment. The lowest yield was obtained in the weedy check followed by T5 (fenoxaprop + almix) and T6 (bispyribac + fenoxaprop) treatments, which suggest some antagonistic effect of tank mixture.

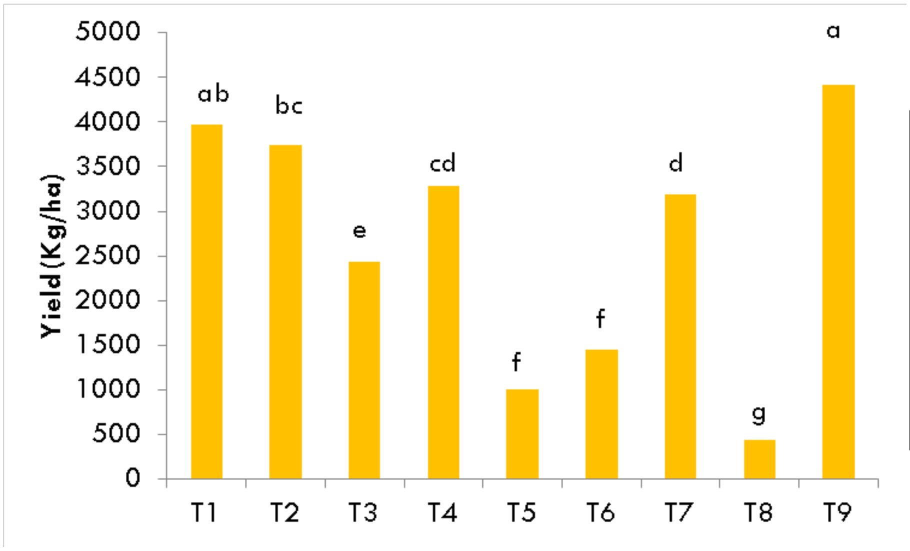
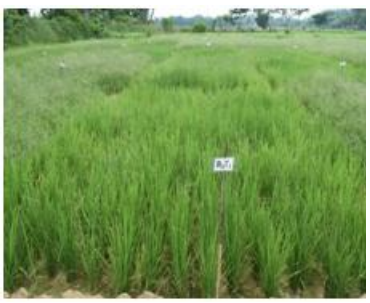
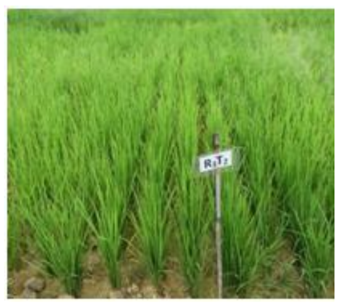


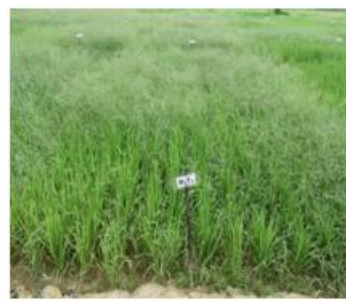
Figure 9. Rice grain yield under different herbicide-based weed control treatments during the 2019 wet season at VBU, Santineketan, West Bengal.



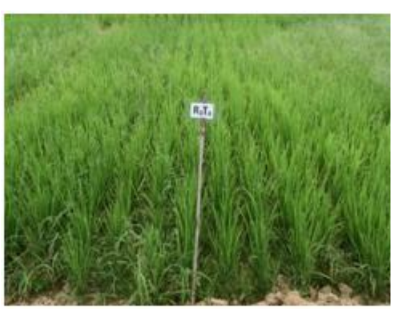
T1= Pendi fb bispyribac



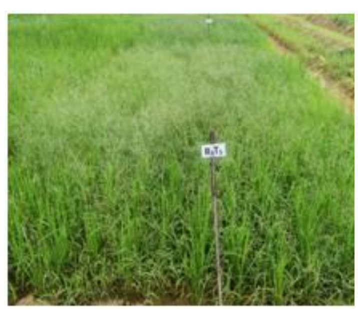
T2 = Oxadiargyl fb bispyribac



T3 = Novlect



T4 = Fenoxaprop + ethoxy



T5 = Fenoxaprop + Almix

T7 = Penoxsulam + fenoxaprop

Inset: Performance of different herbicide-based treatments on weed control

Experiment 3: EFFECT OF SOIL MULCHING ON RICE YIELDS AND WEED CONTROL IN DIRECT-SEEDED RICE

See section 1.4 for the rationale of the soil mulching, which is more important in rainfed systems.

Collaborating scientist: Dr. B. Duary, Visva-Bharti University (VBU), Sriniketan, West Bengal

Location of the Experiment: same as Experiment 1 (VBU), Sriniketan, West Bengal, India).

Treatments:

Main plot: sowing methods (2):

- **M1.** Soil mulching/vattar sowing (Sowing of dry-DSR after pre-sowing irrigation under vattar conditions)
- **M2.** Sowing in dry conditions followed by irrigation

Sub-plot: weed management (6):

- W1. Pre-emergence application of oxadiargyl (Topstar 80 WP) at 90 g ai ha^{-1}
- W2. Post emergence application of bispyribac-sodium at 25 g ai ha^{-1}
- W3. Pre-emergence application of oxadiargyl (Topstar 80 WP) at 90 g ai ha^{-1} fb. post emergence application of bispyribac-sodium at 25 g ai ha^{-1}.
- W4. Premix florpyrauxifen-benzyl + cyhalofop (Novlect) at 150 g ai ha^{-1}.
- W5. Premix florpyrauxifen-benzyl + cyhalofop (Novlect) at 150 g. ai ha^{-1} + fenoxaprop-p- ethyl (Ricestar 9 EC) at 60 g. ai ha^{-1}
- W6. Untreated control

Rice variety: MTU 1010
Experimental Design: RCBD
Replication: Three
Date of sowing: June 10, 2019
Plot size: 5.0 m x 4.0 m
Design: Split-plot

Methodology: Same as Experiment 1.

Results:

Digitaria sanguinalis, *Echinochloa colona*, *Ludwigia parviflora*, *Mollugo stricta* and *Cyperus iria* were the major weed species. At 60 DAS, weed density was 33% lower under the *soil mulch/vattar* sowing method (M1) than In the dry sowing *fb* irrigation method (M2) ((Table 9).

Among herbicide treatments, application of pre-mix florpyrauxifen-benzyl + cyhalofop (Novlect) + fenoxaprop-p-ethyl (Ricestar) recorded the lowest weed density and biomass at 60 DAS followed by oxadiargyl fb bispyribac and bispyribac alone (Table 9). In Novlect + Ricestar treated plots, weed density and biomass was lower (42-46% grasses, 36% broadleaved, 36% sedges, and 33- 37% total weeds) in M1 (*soil mulching/vattar* method) than in M2 (dry-sowing fb irrigation).

Similarly, in the bispyribac-sodium treated plots (W2), weed density was 65-70% lower in M1 (soil mulch/*vattar* sown plots) than in M2.

DSR yield under *soil mulching/vattar* sowing method (M1) was about 9% higher than under the dry-seeding fb irrigation method (M2) (Fig. 10). This may have occurred partly due to better weed control with soil mulching (Table 9). Among weed management treatments, irrespective of the DSR sowing method, yields were highest in the PRE fb POST (W3) and tank mix combination of Novlect + Ricestar as total POST (W5); yields under both treatment were on par. This shows that the total POST herbicide program can produce yields similar to PRE fb POST. In other weed management treatments with either only PRE (W1) and only total POST (W2 and W4), yield was 19-24% and 23-28% lower than PRE fb POST (W3) and the best total POST treatment (W5), respectively (Fig. 10). When weeds were not controlled, yield was 526 kg ha^{-1}, whereas yield increased to 2662 to 3701 kg ha^{-1} when weeds were controlled with different herbicide-based treatments. These results demonstrated that Novlect + Ricestar could be a potential new tank-mixture for controlling complex weed flora in DSR.

Table 9. Weed density and biomass under different dry-DSR sowing methods and weed management treatments at VBU, Sriniketan, West Bengal, during the 2019 wet season[1].

Treatments	Weed density (No m^{-2}) at 60 DAS								Weed biomass(g m^{-2}) at 60 DAS							
	Grass		BLW		Sedge		Total		Grass		BLW		Sedg		Total	
Sowing Method																
M1	99	b	67	a	3	a	171	b	99	b	20	a	3	b	127	b
M2	183	a	66	a	5	a	257	a	171	a	23	a	5	a	202	a
Weed management practices																
W1 (Oxadiargyl)	139	b	35	d	4	b	178	cd	174	b	8	d	4	b	186	bc
W2 (Bispyribac)	138	b	71	b	1	c	210	c	133	bc	10	d	1	c	144	cd
W3 (Oxa fb Bispy)	101	c	52	c	0	c	153	d	108	c	11	d	0	c	119	d
W4 (Novlect)	166	b	80	b	5	b	258	b	147	bc	41	b	5	b	197	b
W5 (W4+Ricestar)	66	d	32	d	0	c	102	e	39	d	15	c	0	c	54	e
W6 (Untreated)	250	a	160	a	28	a	440	a	244	a	69	a	27	a	341	a

[1] *Within column means followed by the same letter are not statistically different at 5% level of probability using LSD test.*

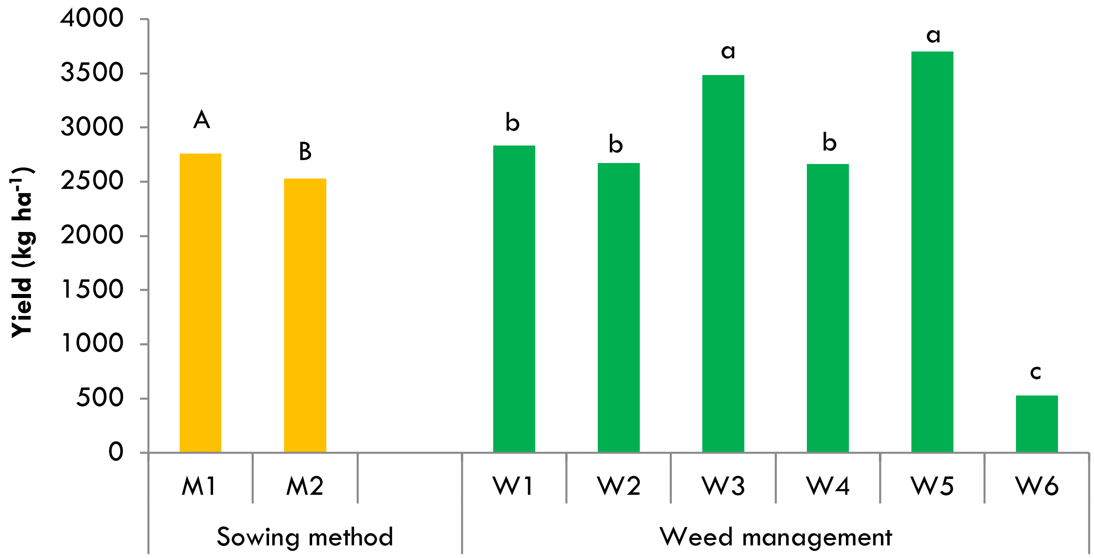


Figure.10. Rice yields in DSR under two sowing methods and weed management treatments during the 2019 wet season.
*Different uppercase letters indicate significant different in DSR sowing methods.
**Different lowercase letters indicate significant difference among weed management treatments.

Experiment 4: EVALUATION OF HERBICIDES WITH DIFFERENT MODES OF ACTION ON WEED CONTROL AND RICE YIELD IN DIRECT-SEEDED RICE

Collaborating Scientist/s: Dr. Sanjay Saha and Dr. Himanshu Pathak, ICAR-NRRI, Cuttack

Location of study: ICAR-National Rice Research Institute, Cuttack (20.50 N, 860E & 23.5 m MSL)

Rice environment: Rainfed shallow lowland & irrigated ecology

Objective of the study: Strengthening integrated weed management framework to avoid risk of evolution of herbicide resistance

Treatments:

Treatments	Treatment description
T1	Pendimethalin (750g ai ha^{-1}) PRE 3 DAS *fb* pre-mix florpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12 EC) as POST at 20 DAS (150g ai ha^{-1})
T2	Pendimethalin (750g ai ha^{-1}) PRE *fb* fenoxaprop-p-ethyl (Ricestar) + ethoxysulfuron (Sunrice) [50 + 15 g ai ha^{-1}] as POST at 20DAS
T3	Pendimethalin (750g ai ha^{-1}))as PRE 3 DAS *fb* bispyribac sodium (30 g ai ha^{-1}) as POST at 20 DAS
T4	Pendimethalin (750g ai ha^{-1}) PRE at 3 DAS) *fb* penoxulam + cyhalofop butyl (130g ai ha^{-1}) 20 DAS
T5	Pre-mix Fflorpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12 EC) (150 g ai ha^{-1}) as early POST at 12-15 DAS
T6	Pre-mix florpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12 EC) (180 g ai ha^{-1}) as early POST at 12-15 DAS
T7	Pre-mix florpyrauxifen-benzyl + cyahalofop-butyl (Novlect 12 EC) + pendimethalin (150 + 500 g ai ha^{-1}) as early POST at 12-15 DAS
T8	Tank mix fenoxaprop (Ricestar) + ethoxysulfuron (Sunrice) (50 +15 g ai ha^{-1}) as early POST at 12-15 DAS
T9	Tank mix fenoxaprop (Ricestar) + ethoxysulfuron (Sunrice) + pendimethalin (50 + 15 + 500 g ai ha^{-1}) as early POST at 12-15 DAS
T10	Weed free
T11	Weedy

Sowing date: June 17, 2019

Variety: Naveen

Experimental design: Randomized complete block design with three replications

Results

The presence of weeds created a 44% reduction in grain yield (Fig. 11). The weed-free treatment produced the highest yield followed by pendimethalin fb penoxsulam + cyhalofop (Vivaya(T4)) or Novlect (T1) or fenoxaprop + ethoxysulfuron (T2). In these treatments, yield was only 8-12% lower than under weed-free conditions. These results suggest that the herbicide treatments (T1-T6) with different modes of action were on par and provided satisfactory weed control, and that they would be useful for farmers to rotate to avoid development of herbicide resistance. Novlect alone (T5 and T6) also gave reasonable yields, with yields that were only 5-8% than those observed when it was applied in sequence to pre-emergence herbicide (T1). Use of these herbicides may be complemented with one spot-hand weeding to further improve the yield so that it is similar to the weed-free treatment. This will also reduce the risk of evolution of herbicide resistance.

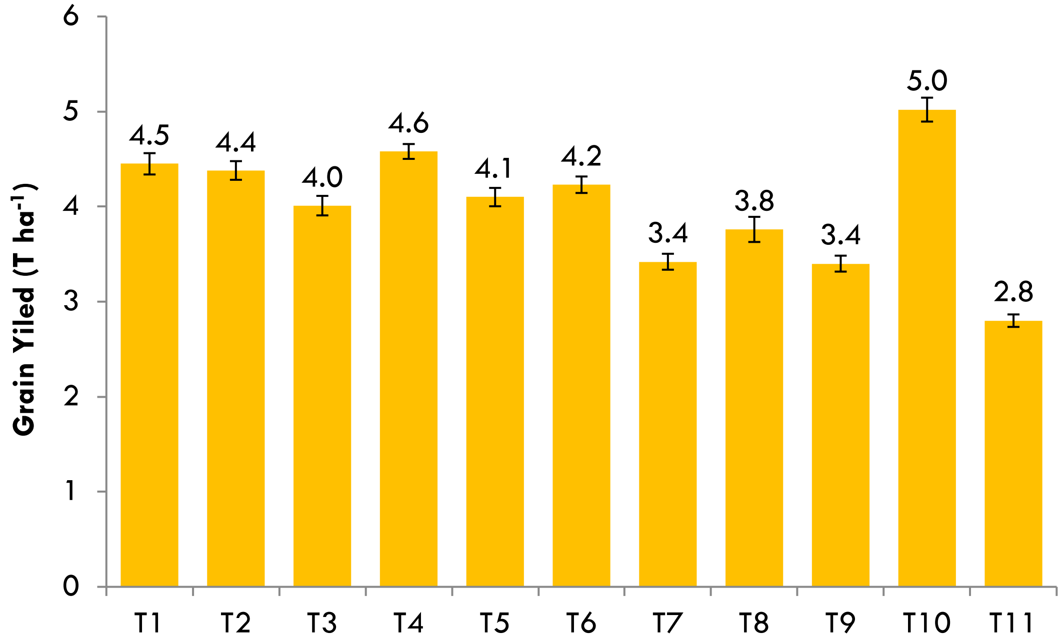
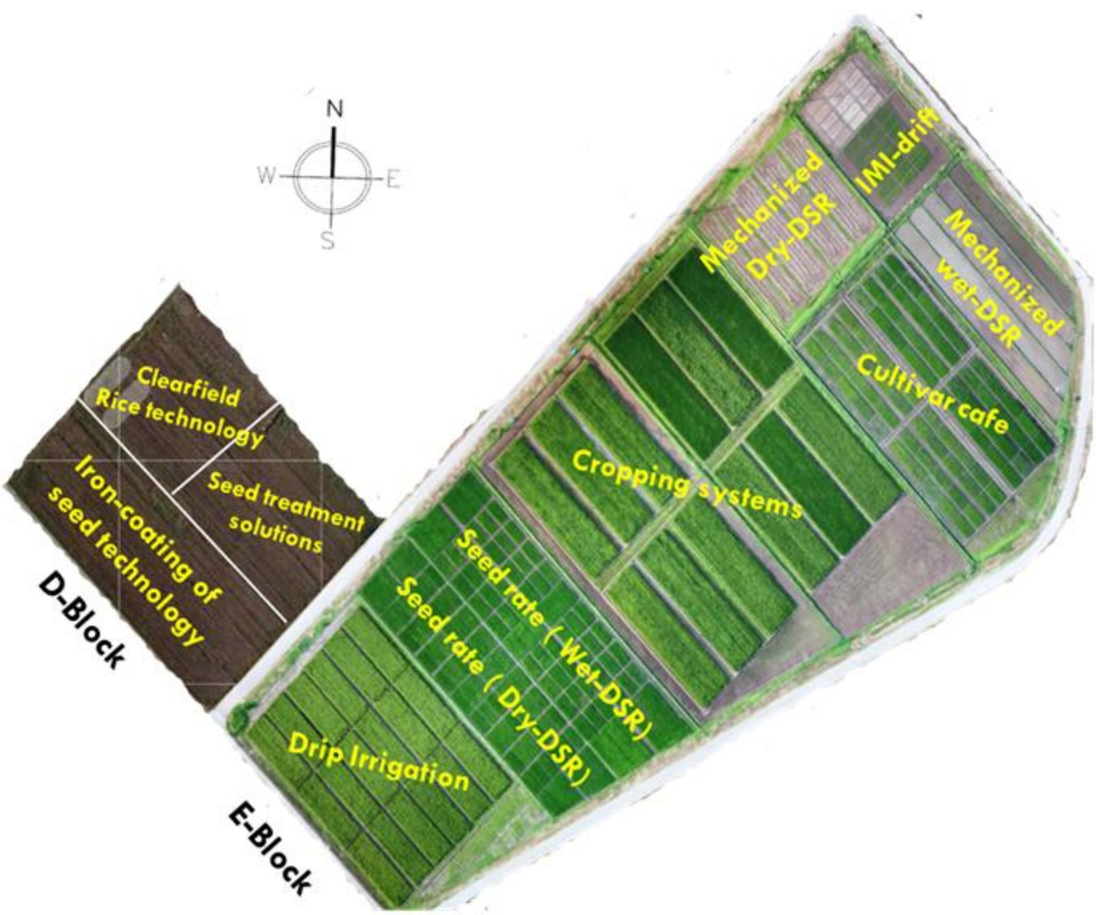


Figure11. Rice grain yield under different weed management treatments at NRRI Cuttack, India, during the 2019 wet season.

2. IRRI HQ, Philippines

At IRRI HQ, a DSR Field Laboratory occupying a total area of 6 ha has been established in the D and E blocks of the IRRI Research Farm to conduct experiments on production-scale plots (see inset below). Using this facility, a multi-disciplinary team of IRRI scientists are working closely with partners/members to address the complex issues associated with DSR. The specific objectives of the DSR Field Laboratory are as follows:

- Showcasing advanced DSR technologies and practices
- Conducting strategic research to close knowledge gaps related to DSR
- Enhancing cross-thematic collaboration to address complex issues of DSR
- Creating a platform to engage various stakeholders in order to encourage awareness (e.g., among donors, policymakers, potential members, media, trainees of IRRI Education, and farmers)
- Capacity building for students and young researchers in the area of DSR to develop the next generation of rice scientists



Inset: DSR Field Laboratory at IRRI HQ, Los Baños, Philippines

During the 2018-19 dry seasons (DS) and the 2019 wet season (WS), the following experiments were conducted at the DSR Field Laboratory at IRRI HQ:

1. Optimizing seed rate for wet- and dry-DSR
2. Optimizing drip irrigation under dry-DSR
3. Evaluating varietal yield and weed competitiveness under dry-DSR
4. Assessing the role of iron coating of rice seed technology to facilitate modified water-seeding of rice
5. Evaluating the multi-criteria performance of continuous DSR-based cropping systems in the short to medium term
6. Assessing the potential benefits and risks of herbicide-tolerant rice technology (Clearfield rice)
7. Evaluating the performance of seed treatment solutions on crop establishment, yield, and pest injuries
8. Developing integrated options for weedy rice management
9. Developing weed management options for DSR

The key results of these experiments are given below.

2.1. Optimizing Seed Rate for Wet- and Dry-DSR

Rationale: A wide range of seed rates are practiced in Asia. In Southeast Asia (e.g., Malaysia, Cambodia, Thailand, Vietnam, and the Philippines) and South Asia (e.g., Sri Lanka). In countries where DSR has been widely practiced, the seed rate ranges from 100 to 350 kg ha^{-1} and DSR is widely established using manual broadcast.

High seed rates are generally used partly to suppress weeds; to compensate for damage caused by birds, rats, and insects; and to compensate for poor stand establishment when using the broadcast method. However, based on results from India and China for mechanized DSR, a seed rate of 20-25 kg ha^{-1} can produce yields similar to broadcast DSR or transplanted rice. Moreover, limited data is available on the effect of seed rate and DSR establishment methods (broadcast versus line sowing). Therefore, it is important to identify the optimum seed rate for both the line sowing and broadcast methods under dry and wet seeding conditions.

Objectives:

1. To identify the optimum seed rate for broadcast and line-sown dry-DSR
2. To identify the optimum seed rate for broadcast and line-sown wet-DSR

Treatments:

Two separate trials (factorial) were conducted, one for dry seeding and the other for wet seeding in the G of the Research Farm at IRRI HQ (see DSRC field laboratory layout map).

Factor 1: Seed rate (6)

- 20, 40, 60, 80, 120, 200 kg ha^{-1}

Factor 2: Crop establishment method (2)

- Line sowing
- Broadcast method

Plot size: 4 m x 8 m = 32 m2

Experimental design: Randomized complete factorial design with four replications

Materials and Methods: The crop management practices used in wet- and dry-DSR seed rate experiments are summarized in Table 10.

Table 10. Summary of crop management practices used in dry- and wet-DSR seeding rate experiments in the 2019 DS and 2019 WS at IRRI HQ, Los Banos, Philippines.

	Dry-DSR	Wet-DSR
Land preparation	The field was dry tilled and laser leveled. The field was not puddled.	The field was prepared using both dry and wet tillage. A laser-leveled field was puddled.
Seed preparation and seed treatment	Dry seeds were used. Seeds were treated with imidacloprid (Gaucho).	Seeds were soaked for 24 hrs, then incubated for 24 hrs, after which the pre-germinated seeds were sown. Seeds were treated with imidacloprid (Gaucho)
Sowing date	February 15 (2019 DS); July 14 (2019 WS)	
Variety	RC-18	
Fertilizer (N: P_2O_5: K_2O)	160:30:40 (2019 DS); 140:40:40 (2019 WS)	
Weed management	Pre-emergence (pretilachlor with safener) followed by post-emergence (bispyribac-sodium)	
Pest management	No insecticide or fungicide applied	
Crop establishment*	Line sowing: Using a plot planter with 20-cm row spacing Broadcast: manual broadcast	Line sowing: Manually done in line with 20-cm row spacing Broadcast: manual broadcast
Irrigation	To ensure optimum germination and seedling establishment, rice was irrigated as needed for the first 2-3 weeks and subsequent irrigation was applied at 10 kPa soil matric potential (SMP) at 15 cm soil depth. Tensiometers were installed to monitor SMP.	To ensure optimum germination and seedling establishment, rice was irrigated as needed for the first 10 days, then kept flooded for 2 weeks and subsequent irrigation was applied at 10 kPa soil matric potential at 15 cm soil depth. Tensiometers were installed to monitor SMP.

Results:

A) Wet-DSR

In the 2019 DS, irrespective of seed rate, rice grain yield was 0.4 t ha^{-1} (8%) lower in the broadcast DSR method than in the line-sown DSR method (Table 11). Irrespective of establishment method, yields were similar, with seed rates ranging from 20 to120 kg ha^{-1} but declined at 200 kg ha^{-1}. When a seed rate of 200 kg ha^{-1} was used, on an average, rice yield declined by 8 to 15% (0.4 to 0.7 t ha^{-1}) compared to lower seed rates.

The effect of seed rate varied with establishment method, as demonstrated by the significant interaction effect of seed rate x establishment method. In the broadcast DSR method, results were more variable, with the lowest yields at the 20 kg ha^{-1} and 120 kg ha^{-1} seed rates and the best yields observed in the range of 40 - 80 kg ha^{-1}. In contrast, in line-sown DSR, yields did not differ with seed rates from 20-120 kg ha^{-1} but declined at 200 kg ha^{-1}.

Table 11. Rice yield (t ha^{-1}) under different seed rates and establishment methods under wet-DSR during the 2019 DS at IRRI HQ

Seed Rate	Establishment method		Average
	Broadcast	Line sowing	
20	4.79 b[1] B	5.85 a A[2]	5.32 a
40	5.44 a A	5.51 a A	5.47 a
60	4.95 ab A	5.47 a A	5.21 ab
80	5.44 a A	5.60 a A	5.52 a
120	4.62 b B	5.72 a A	5.17 ab
200	4.97 ab A	4.60 b A	4.79 b
Average	5.04 B	5.46 A	
	ANOVA (p-value)		
Method (M)	0.0020		
Seed Rate (SR)	0.0271		
SRxM	0.0110		

[1]*Within column means followed by the same lowercase letter are not statistically different at 5% level of probability.*

[2]*Within row means followed by the same uppercase letter are not statistically different at 5% level of probability.*

In the 2019 WS, both seed rate and establishment methods affected rice grain yield, but the **in the 2019 WS,** both seed rate and establishment methods affected rice grain yield, but the interaction effect was not significant (Table 12). Irrespective of seeding rate, the line-sown DSR produced yields 1.3 t ha^{-1} higher than broadcast DSR. Among seed rates, yields were similar and higher with seed rates in the range of 20-60 kg ha^{-1}; yields declined 20-25% (0.6 to 0.8 t ha^{-1}) at seed rates in the range of 80-200 kg ha^{-1}.

These results clearly demonstrated that line-sown DSR produced greater yields than broadcast-DSR, and that lower seeding rates (20-80 kg ha^{-1}) can produce yields that are the same or higher compared to higher seeding rates (120-200 kg ha^{-1}). This suggests the potential for savings in terms of seed and seed cost.

Table 12. Rice yield (t ha^{-1}) under different seed rate and establishment methods under wet-DSR during the 2019 WS at IRRI HQ

Seed Rate	Establishment method		Average
	Broadcast	Line sowing	
20	3.36	4.51	3.93 a[1]
40	3.46	4.39	3.92 a
60	2.90	4.67	3.79 ab
80	2.52	4.04	3.29 bc
120	2.56	4.02	3.28 bc
200	2.68	3.63	3.15 c
Average	2.91 B[2]	4.21 A	
	ANOVA (p-value)		
Method (M)	<0.001		
Seed Rate (SR)	0.0100		
SRxM	NS		

[1] Within column means followed by the same lowercase letter are not statistically different at 5% level of probability

[2] Within row means followed by the same uppercase letter are not statistically different at 5% level of probability

B) Dry-DSR

In the 2019 DS, the dry-DSR yield was not influenced by seeding rates (Table 13). For example, rice yields were similar for seed rates ranging from 20 to 200 kg ha^{-1}). In contrast, establishment method influenced rice yield with a 1.0 t ha^{-1} (28%) higher yield observed in line-sown DSR than in broadcast DSR.

Table 13 . Rice yield (t ha^{-1}) under different seed rates and establishment methods under dry-DSR during the 2019 DS at IRRI HQ

Seed Rate	Establishment method		Average
	Broadcast	Line sowing	
20	3.62	4.46	4.04 a[1]
40	3.60	4.71	4.16 a
60	3.90	5.08	4.49 a
80	3.18	4.35	3.76 a
120	3.82	4.84	4.33 a
200	3.46	4.25	3.85 a
Average	3.60 B[2]	4.61 A	
		ANOVA (p-value)	
Method (M)		<0.001	
Seed Rate (SR)		0.084 (NS)	
SRxM		0.9624 (NS)	

[1]Within column means followed by the same lowercase letter are not statistically different at 5% level of probability'
[2]Within row means followed by the same uppercase letter are not statistically different at 5% level of probability.

The effect of seed rate did not vary with establishment method as demonstrated by non-significant seed rate x establishment method interaction.

For the 2019 WS, in contrast to the 2019 DS, the results showed no effect of establishment method on rice grain yield; however, yield declined at higher seeding rates (Table 14). For example, irrespective of establishment method, the yields were similar with seeding rates of 20 -120 kg ha^{-1}, but the yield declined more at 200 kg ha^{-1} than at 20 kg ha^{-1}. The effect of seeding rate varied with establishment method as demonstrated by the significant interaction effect of seed rate x establishment method (p-value = 0.0036). For example, in broadcast DSR, yield did not differ with seeding rates ranging from 20 to 200 kg ha^{-1}, whereas in line-sown DSR, yields were similar at seeding rates of 20-80 kg ha^{-1} but declined at higher seeding rates of 120 and 200 kg ha^{-1} compared to lower seeding rates of 20-80 kg ha^{-1}.

Table 14 . Rice yield (t ha^{-1}) under different seed rates and establishment methods under dry-DSR during the 2019 WS at IRRI HQ

Seed Rate	Establishment method		Average
	Broadcast	Line sowing	
20	3.61 a[1] B[2]	4.45 a A	4.03 a
40	3.00 a B	4.29 a A	3.65 ab
60	3.77 a A	3.49 bc A	3.63 ab
80	3.12 a A	3.90 ab B	3.51 ab
120	3.67 a A	2.92 c B	3.29 ab
200	3.16 a A	2.86 c A	3.01 b
Average	3.39	3.65	
	ANOVA (p-value)		
Method (M)	NS		
Seed Rate (SR)	0.0176		
SRxM	0.0036		

[1]Within column means followed by the same lowercase letter are not statistically different at 5% level of probability.

[2]Within row means followed by the same uppercase letter are not statistically different at 5% level of probability

2.2. Varietal Evaluation for Yield and Weed Competitiveness Under Dry-DSR Conditions

Significant progress has been made in the agronomy of DSR and further refinement will continue to be important. However, identifying cultivars suitable for DSR conditions is an equally critical factor in improving the potential of DSR systems. Cultivars with the following characteristics are desirable for DSR: high-yielding with shorter duration; weed suppressive; resistant to insect-pests, diseases and lodging; and adapted to mild stresses, including moisture and nutrient stresses.

This study was conducted to evaluate the most common hybrids and inbred rice cultivars in the Philippines for yield and weed competitiveness under dry-DSR conditions.

Treatments: Total 20 cultivars including hybrid and inbred

- **Hybrids (10):**
  - **IRRI Hybrids:** Mestiso 68, Mestiso 61, Mestiso 71, Mestiso 77, Mestiso 89,
  - **Corteva hybrids:** PHB-83, PHB-79,
  - **Bayer hybrids:** Arize Bigante Plus, AZ 8433 DT, Arize Habilis
- **Inbred (10):**
  - From the rainfed breeding program: IR16L1726, IR16L1743, IR16L1730
  - From GSR program: GSR 12, NSIC RC 436, NSIC RC 480,
  - From the irrigated program: IRRI 154, IRRI 174
  - Control cultivars for quality trait: CSR 36, CSR43

Replications: 4

Design: Randomized complete block

Method: Twenty rice cultivars were sown under dry-DSR conditions using a limit plot planter at a seed rate of 30 kg ha^{-1}. The plot size was 4 m x 8 m. In the dry season, DSR was sown on February 23, 2019; the wet season DSR was sown on July 20, 2019. The plots were kept weed free using pre-emergence fb post-emergence application of herbicide + hand weeding. To assess the weed competitiveness of these cultivars, purple rice was sown as a surrogate weed between two rice rows in a one-meter running row at 5 DAS, 15, DAS, and 30 DAS in 4 locations per plot for each timing. Two random running rows of purple rice were harvested 60 days after rice sowing, and the remaining two running rows of purple rice were harvested once the crop reached physiological maturity. Other observations taken at regular intervals were crop biomass, tiller density, plant height, and canopy cover. Yield and yield attributes were also estimated.

The problem encountered: In the 2019 DS, some of the cultivars were attacked by leaf folder at the late stage (reproductive stage) of the crop, especially the relatively longer duration hybrid cultivars (e.g., Arize Bigante Plus and AZ8433 DT). In addition, these longer duration cultivars suffered more from higher temperatures at the grain-filling stage as the rice was planted late (at the end of February), which pushed grain-filling to a high temperature period. Longer duration cultivars in particular suffered higher spikelet mortality and produced more unfilled grain.

Additionally, two cultivars (Mestizo 61 and Arize Bigante Plus) showed very poor crop establishment due to poor germination of the seed lot. In wet season 2019, longer duration cultivars (i.e., Arize Bigante Plus, AZ84433, and AZ84433) were harvested prior to physiological maturity due to the typhoon Ramon warning/threat; hence the yields for these cultivars were low and underestimated.

Results:

Yield: Grain yield of rice cultivars differed significantly in the dry and wet seasons (Figure 12). Rice hybrid V4 produced the highest grain yield (5.3 t ha^{-1}), but the yield was statistically similar to the inbred cultivars V9 (5.1t ha^{-1}), V10, V12, and V18, all of which had yields in the range of 4.9-5.1t ha^{-1} (Figure 12A). This was followed by hybrid V5 (4.8 t ha^{-1}) and inbred V11 (4.7 t ha^{-1}). The low-yielding cultivars during dry season were mostly hybrids, such as V14, V15, V17, and V3 (results are in contrast to those found in wet season 2018 results), and inbreds, such as V19, V6 and V8 (for which yields were consistent with wet season 2018 results). Based on contrast analysis, yields of inbred cultivars were 10 % higher compared to hybrid cultivars (4.0 t ha^{-1}vs 4.5 t ha^{-1}) in dry season 2019 (Fig. 13A). These lower yields were primarily due to infestation by leaf folder in the later stages of long-duration hybrid cultivars and terminal heat stress due to higher temperatures during the grain filling stage linked to late planting of the trial at the end of February.

In the 2019 wet season, the high-yielding hybrids were V16, V17, and V4, and the high-yielding inbreds were V10, and V11 (Fig. 12 B). Rice hybrids V14, V15, V1 and V5 were observed to be low yielding. Rice inbreds V7, V12, V13, and V6 were also found to be low yielding. Based on contrast analysis, the yield of inbred and hybrid cultivars did not differ significantly (Fig13 B). It is important to note that the yields of longer duration hybrids were more affected by typhoon as these were harvested prior to physiological maturity to avoid damage from the expected typhoon. The V4 (hybrid) and V10 (inbred) cultivars performed well in both the dry and wet seasons. Both cultivars exhibited good crop establishment in both dry and wet seasons.

In both seasons, longer duration hybrid cultivars were disadvantaged. In the 2019 DS, their grain filling was pushed when the temperature was high and unfavorable for grain filling; these hybrid cultivars were also more frequently attacked by leaf folder during the reproductive phase, resulting in less grain filling and a lower harvest index. During the 2019 WS, at the time of the typhoon, most of the cultivars had reached the physiological maturity stage, except some of the longer duration hybrid cultivars (e.g., Arize Bigante Plus, and AZ84433). These hybrids had reached the grain filling stage but were harvested prior to physiological maturity; hence their yields were low. These factors may have contributed to the inconsistencies in the yield results compared to results of an experiment performed in an earlier season (the 2018 wet season), in which hybrids outperformed inbreds.

Purple rice biomass: In general, hybrid cultivars suppressed the growth of purple rice more than inbred rice cultivars, which suggests their competitiveness (Fig. 14, 15, and 16). At both timings (purple rice sown at 5 and 15 DAS), hybrids suppressed the purple rice biomass more than inbred cultivars. When sown at 30 DAS, purple rice could not compete with any of the cultivars (data not shown).

When sown at 5 DAS and harvested at 60 DAS, the purple rice biomass was 20% and 25% lower under hybrids than inbreds in the 2019 DS and 2019 WS, respectively (Fig. 14). When harvested at physiological maturity, purple rice biomass under hybrid cultivars was 43 % and 26 % lower than under inbred cultivars during the dry and wet seasons, respectively (Fig. 15). The biomass of purple rice seeded at 15 DAS and harvested at 60 DAS was 41 % and 23 % lower under hybrids compared to inbreds in the 2019 DS and 2019 WS, respectively (Fig. 16).

These results demonstrated that the yield performance of hybrids was variable across season; however, hybrids consistently suppressed purple biomass more than inbreds, suggesting higher weed-suppressive capabilities.

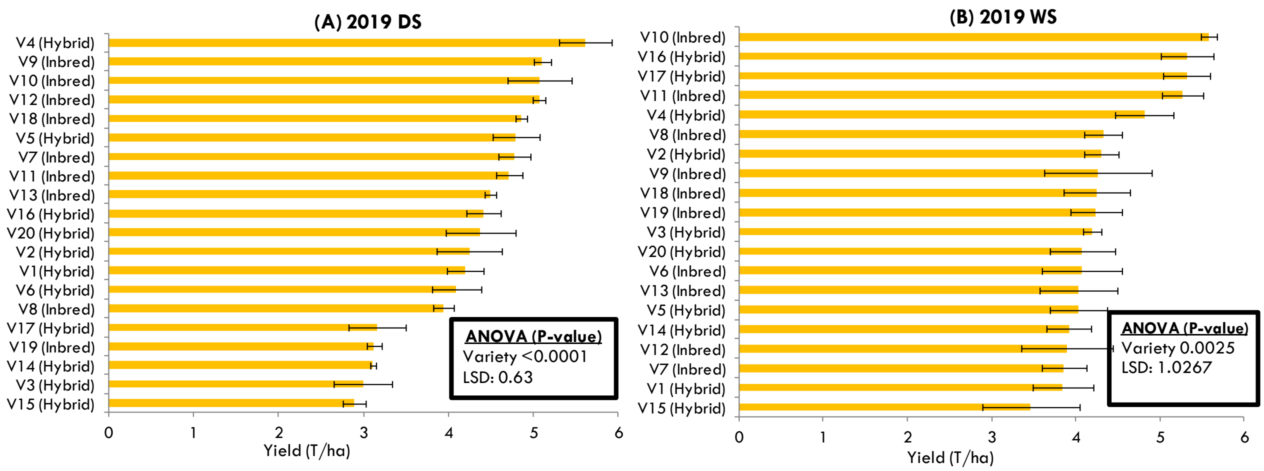


Figure 12. Yields (t ha^{-1}) of 20 rice cultivars grown under dry-DSR conditions during (A) 2019 DS and (B) 2019 WS at IRRI HQ.

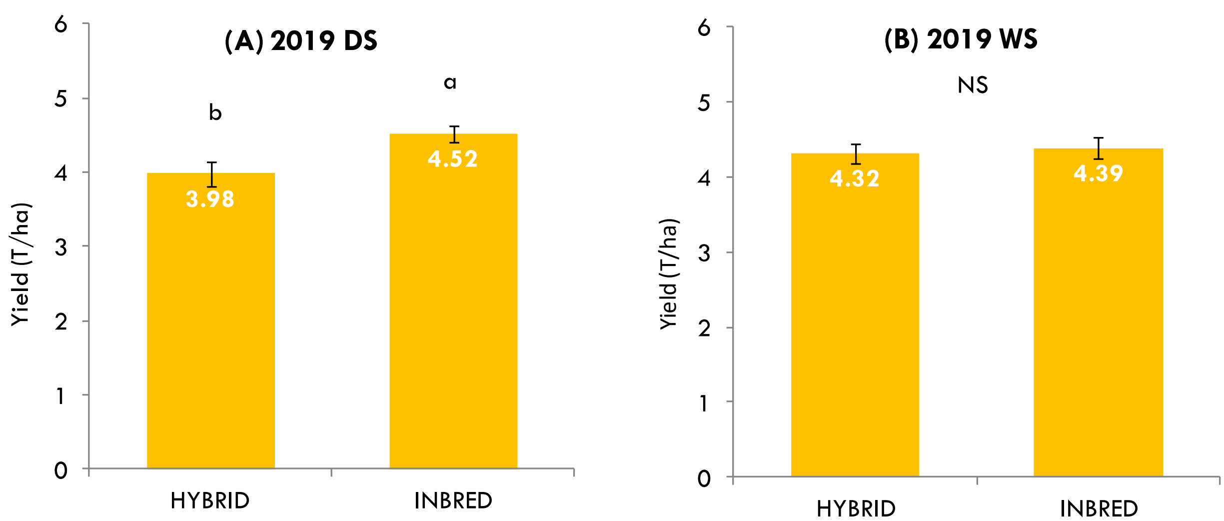


Figure 13. Contrast analysis for rice grain yield (t ha^{-1}) of hybrid versus inbred cultivars under dry-DSR during (A) 2019 DS and (B) 2019 WS at IRRI HQ. Different letters indicate significant differences in the treatments using Tukey's HSD test.

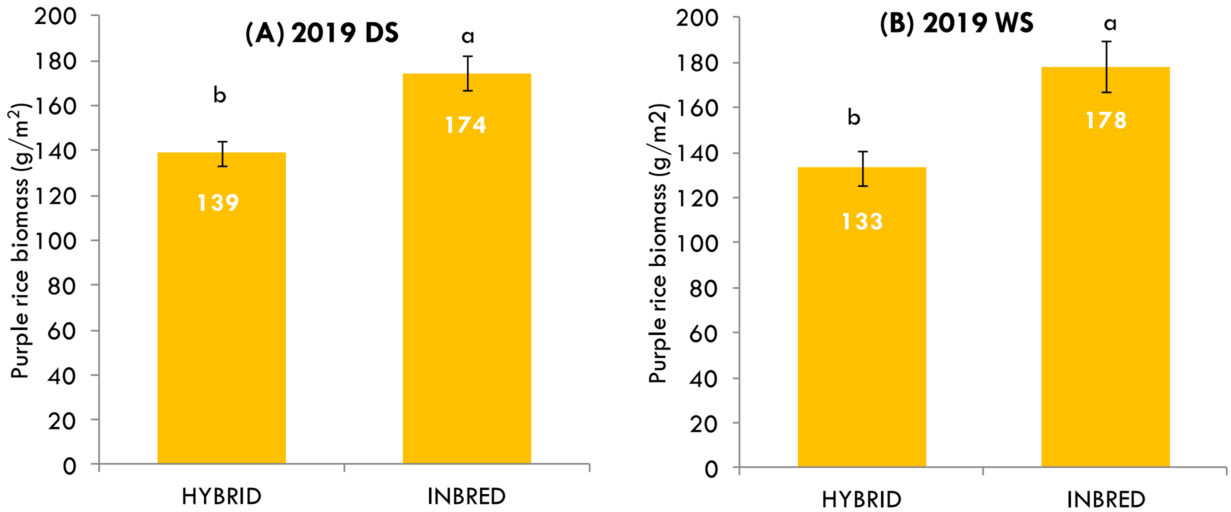


Figure 14. Purple rice biomass (g m^{-2}) grown under hybrid and inbred cultivars when sown 5 days after rice sowing (DAS) and harvested at 60 DAS during (A) 2019 DS and (B) 2019 WS. Different letters indicate a significant difference in treatments using Tukey's HSD test.

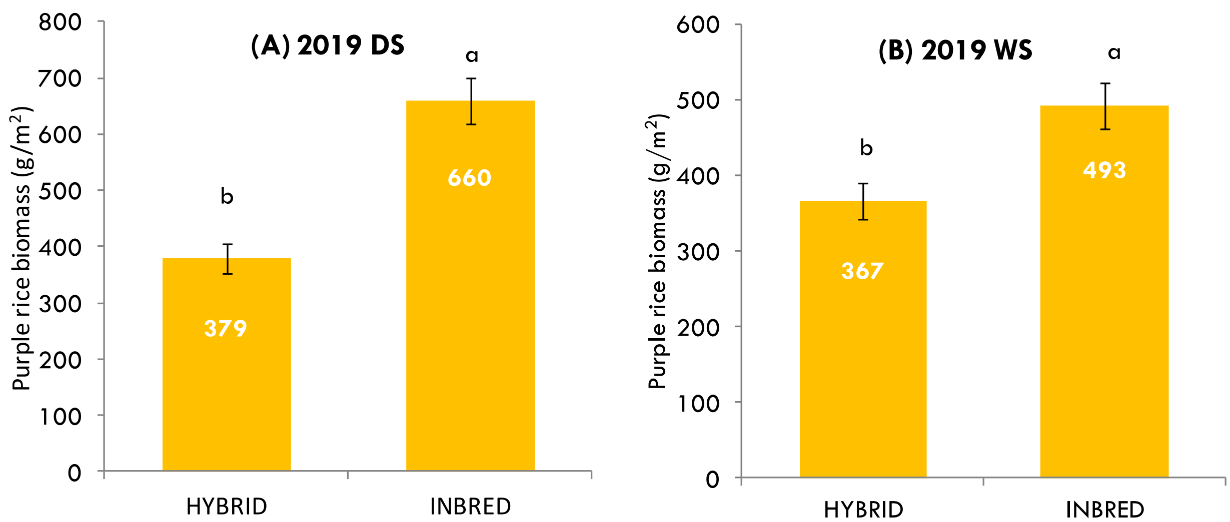


Figure 15. Purple rice biomass (g m^{-2}) under different rice varieties when sown 5 days after rice sowing and harvested at physiological maturity (A) DS 2019 and (B) WS 2019. Different letters indicate significant difference in treatments using Tukey's HSD test.

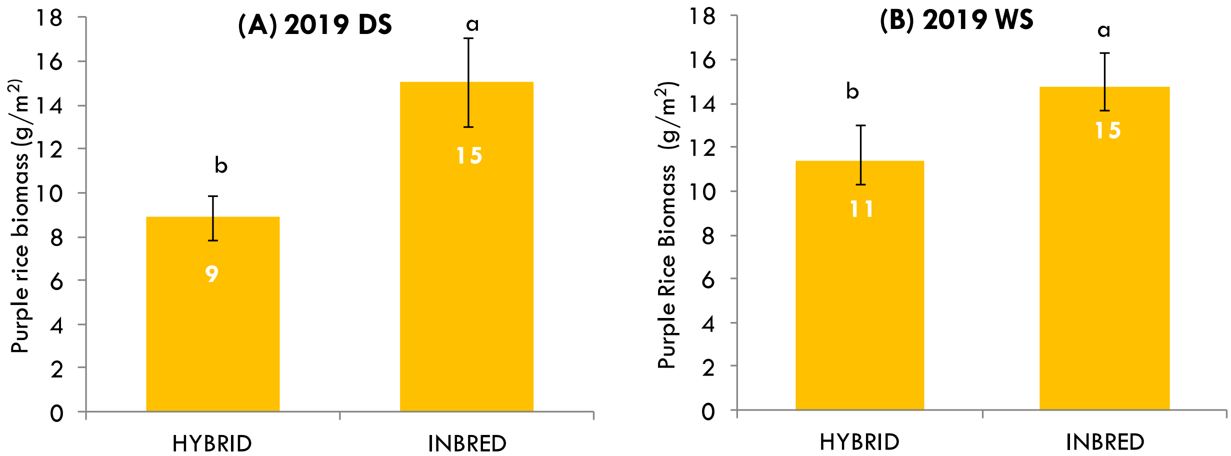


Figure 16. Purple rice biomass (g m^{-2}) under different rice varieties when sown 15 days after rice sowing and harvested at 60 DAS (A) DS 2019 and (B) WS 2019. Different letters indicate significant difference in treatments using Tukey's HSD test.

Path analysis to identify traits responsible for weed suppression

The path analysis was performed using data on purple rice sown at 5 DAS and harvested at 60 DAS from the 2018 WS and 2019 DS, and did not include data from the 2019 WS (full data is still being processed). The path coefficient schematic diagram (Fig. 17 A & B) shows the direct and indirect relationships of plant traits on purple rice biomass, and corresponding coefficients are shown in Tables 15.

Based on the results of the stepwise multiple linear regression analysis, suppression of purple rice biomass was directly affected only by rice biomass at 30 DAS during both wet and dry seasons. Crop establishment (CE), plant height (PH), tiller no. (T), leaf area index (LAI), canopy cover percentage (CN%), relative growth rate (RGR), crop growth rate (CGR), and net assimilation ratio (NAR) appear to indirectly affect weed biomass through rice biomass. The effect of rice biomass on purple rice biomass was -0.45 in the 2018 WS (Figure 17A; Table 15), and -0.73 in the 2019 DS (Figure 17B; Table 15). During the 2018 WS, among plant traits, LAI at 30 DAS had a positive direct effect on rice biomass; hence, it suppressed purple rice biomass indirectly through its positive effect on rice biomass (Table 15). In the 2019 DS, in addition to LAI at 30 DAS, plant height at 30 DAS, tiller number at 15 DAS and RGR from 12 to 24 DAS also exhibited positive effects on rice biomass, and through their effect on rice biomass, ultimately suppressed the purple rice biomass (Table 15). Other plant traits showed no significant effect.

This suggests that early high biomass accumulation by rice could be one of the most important criteria for breeding rice genotypes for weed competitiveness, and using this trait, cultivars can be assessed for their weed competitiveness under weed-free conditions.

Table 15: Estimates of the direct effects (path coefficients) of plant traits on rice biomass and rice biomass on purple rice biomass, sown at 5 days after sowing of rice during the 2018 WS and the 2019 DS

Trait	2018 WS			2019 DS		
	Estimate	SE	Pr. Level	Estimate	SE	Pr. Level
Rice biomass at 30 DAS	**-0.45**	**0.48**	***	**-0.73**	**0.21**	***
Indirect factors contributing to rice biomass at 30 DAS						
CE_{15}	0.14	0.10		-0.27	0.08	***
PH_{20}	-0.09	0.31		0.19	0.32	*
T_{15}	-0.14	0.06		0.34	0.06	*
CN_{14}	0.11	0.55		-0.05	0.78	
LAI_{30}	0.59	5.77	***	0.60	8.52	***
NAR_{30-PI}	-0.17	1322		-0.00	1557	
CGR_{30-PI}	-0.06	0.41		0.04	0.45	
RGR	-0.08	49.51		0.18	43.43	**

*CE_{15} = crop establishment at 15 DAS, PH_{20} = plant height at 20 DAS, T_{15} = tiller number at 15 DAS, CN_{14} = canopy (%) per ground area at 14 DAS, LAI_{30} = leaf area index at 30 DAS, NAR_{30-PI} = net assimilation rate (30 DAS to panicle initiation stage), CGR_{30-PI} = crop growth rate (30 DAS to panicle initiation stage), **RGR** = relative grate rate (12-24 DAS); *** = $p<0.001$*

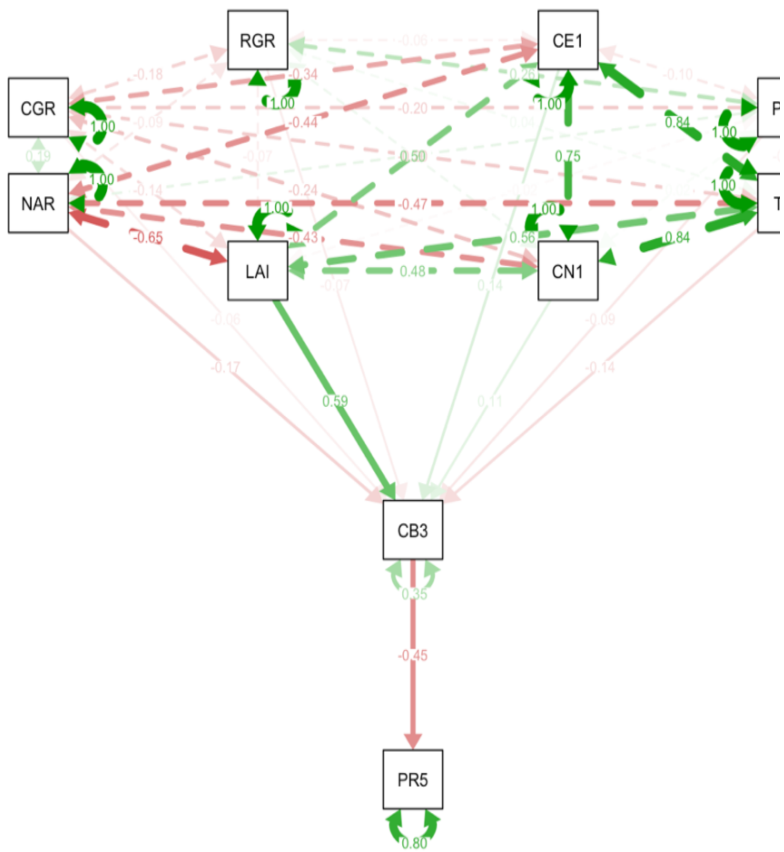


Figure 17 A. Path diagram showing direct and indirect effects of plant traits on purple rice biomass sown at 5 DAS rice (PR5) and harvested at 60 DAS of rice in wet season 2018.

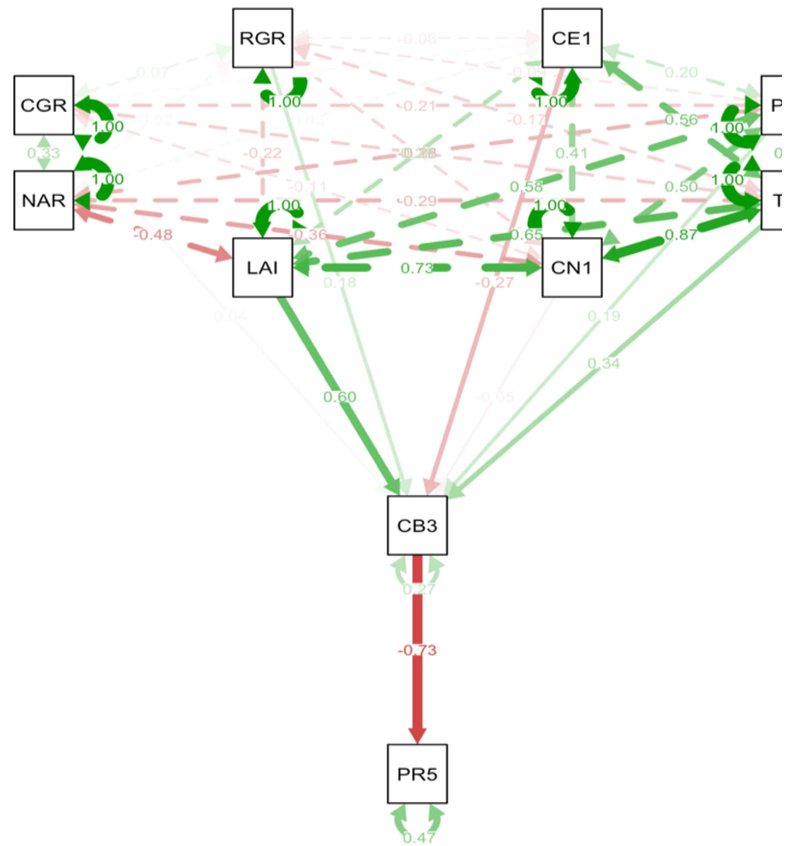


Figure 17 B. Path diagram showing direct and indirect effects of plant traits on purple rice biomass sown at 5 DAS rice (PR5) and harvested at 60 DAS of rice in dry season 2019.

Abbreviations: CB3= rice biomass at 30 DAS, LAI= leaf area index (30 DAS), NAR= net assimilation rate (30-PI), CGR= crop growth rate (30-PI), RGR= relative growth rate (12-24 DAS), CE1= crop establishment at 10 DAS, PH3= plant height at 30 DAS, T15= tillers at 15 DAS, CN1= canopy (%) at 14 DAS.

2.3. Assessing the Potential Benefits and Risks Associated with Herbicide-Tolerant Rice (e.g. Clearfield Rice) in the Philippines

Weed management is the biggest challenge to transitioning from puddled transplanted rice to DSR and achieving the full yield potential of DSR crops. Many weed-related issues have emerged in areas where DSR has been widely adopted, such as proliferation of weedy rice; shifts in weed flora towards difficult-to-control weeds such as *Ishaemum rugosum*, and *Leptochloa chinensis*; and the evolution of herbicide resistance to commonly used herbicides in key weed species.

Herbicide-tolerant rice (HT-rice) can help overcome these issues and may facilitate the adoption of resource-efficient, cost-effective alternatives for rice establishment such as DSR. Some of the key benefits of HT-rice include i) improved weed control with greater flexibility and lower risk of crop phytotoxicity, especially those types associated with rice (e.g., weedy rice); ii) replacement of currently used herbicides with new, more efficient herbicides with better environmental profiles; and iii) new options to manage weeds that have evolved resistance to currently used herbicides.

Despite the benefits of HT-rice, there are some potential risks associated with its use that should be evaluated prior to wide-scale adoption. Potential risks include the following: i) gene flow from HT-rice to wild and weedy rice leading to weediness and invasiveness; ii) the emergence of the volunteer rice problems; iii) the evolution of herbicide resistance with continued use; iv) drift risk to neighboring fields; and v) carryover risk to rotation crops if the herbicide has a high residual effect.

Imidazolinone-tolerant (IMI) rice, commonly known as *Clearfield rice*, is one of the three HT-rice systems developed. The other two HT-rice systems are glyphosate-tolerant (Round-up Ready) and glufosinate-tolerant (Liberty Link). Of these three, only IMI-rice has been commercialized in various countries, including the USA, Brazil, Argentina, Uruguay, Italy, and Malaysia. The demand for this technology is greater in countries where weedy rice has threatened the sustainability of rice production (e.g., Malaysia and Vietnam) and where farmers have struggled to shift from transplanted rice to DSR because of weed issues.

It is likely that IMI-rice may be commercialized in the Philippines in the near future to address weedy rice management, in addition to managing other weed-related issues in DSR. Therefore, two experiments were conducted to assess the potential of IMI-rice (Clearfield rice) technology, both to assess its weed control potential and to examine potential risks associated with IMI-rice so that solutions to manage these risks can be developed.

Experiment 1: EVALUATING THE PERFORMANCE OF CLEARFIELD RICE TECHNOLOGY (IMI-HERBICIDES) FOR WEED CONTROL AND ASSESSING CARRYOVER EFFECT OF IMI-HERBICIDES ON NON-CLEARFIELD RICE VARIETIES UNDER PHILIPPINE CONDITIONS

Treatments for assessing weed control:

1. Pre-mix imazapyr + imazapic in1:3 ratio (ONDUTY 70%WG) at 154 g ai ha^{-1} + adjuvant (Hasten 90%) at 900 g ai ha^{-1} as Pre-emergence (PRE) at 1 day after rice sowing (DAS)
2. Pre-mix imazapyr + imazapic in 3:1 ration (KIFIX 70%WG) at 150 g ai ha^{-1} + adjuvant (Hasten 90%) at 900 g ai ha^{-1}) as early post-emergence (POST) at 10 DAS
3. Pretilachlor with safener at 300 g ai ha^{-1} as PRE at 1 DAS followed by (fb) bispyribac-sodium at 30 g ai ha^{-1} as POST at 15-20 DAS
4. Pre-mix Pyribenoxim + cyhalofop (Pynchor ultra 8.5 EC) 85 g ai ha^{-1} as early POST at 10-12 DAS
5. Non-treated check

Note: The experiment was terminated 70 DAS (prior to booting) to avoid any risk of gene flow.

Treatments to assess carryover effect on non-Clearfield rice variety:

1. Seeding of non-Clearfied Rice (Rc-18) 8 days after termination of Clearfield experiment or 77 days after application of ONDUTY (PRE herbicide) application
2. Seeding of non-Clearfied Rice (Rc-18) 27 days after termination of Clearfield experiment or 96 days after application of ONDUTY (PRE herbicide) application

Plot size: 4 m x 8 m= 32 m2

Rep: 3

Total plots: 5 x 3= 15

Method: Rice was established with the wet-DSR method using drum seeder at the 30 kg ha^{-1} seed rate of the Clearfield rice hybrid. Seeds were soaked for 24 hours and then incubated for 24 hours, after which the pre-germinated seeds were sown. Seeds were also treated with imidacloprid (Gaucho). Land preparation, fertilizer application, and water management were similar to the seed rate experiment for wet-DSR (refer to Table 10 for details).

To assess the effect of IMI-herbicides on weed control, in addition to the naturally occurring weeds in the field, we also seeded 6 weed species in rows along the width of the plot (across the seeding direction/length of plot) in each plot using a fixed number of seeds. Each weed row was separated by 0.5 m. The weed species seeded were as follows: *Echinochloa crus-galli*, *Leptochloa chinensis*, *Ischemum rugosum*, *Cyperus iria, Ludwigia hyssopifolia,* and purple rice (to represent the weedy rice as we are not allowed to seed weedy rice on the IRRI farm).

To assess the carryover effect of IMI-herbicides on normal non-Clearfield rice varieties, after termination of the Clearfield rice experiment for weed control assessment (70 days after sowing prior to heading to avoid any gene flow), a non-Clearfield rice variety (RC-18) was seeded at two timings: 8 and 27 days after termination of the experiment (77 and 96 days after PRE herbicide application of IMI-herbicide in all plots with the five herbicide treatments mentioned above). Prior to sowing the non-Clearfield rice variety, the field was prepared (puddled) as per standard practice. A seed rate of 30 kg ha^{-1} was used and seed was sown using a drum seeder. After first planting (8 days after termination of IMI-herbicide experiment), crop establishment and growth was monitored for 15 days after which the experiment was terminated. The land was again prepared, and a second crop of non-Clearfield rice was planted 27 days after termination of the IMI-herbicide experiment. The crop produced was monitored for next 15 days for phytotoxicity. To assess the phytotoxicity of IMI-herbicide on non-Clearfield rice, the following observations were collected: crop establishment, crop biomass, and plant height at 15 days after sowing.

Results:

A) Effects on weeds: The major natural weed species present in the field in order of decreasing ranking were as follows: *Cyperus difformis*, *Fimbristylis miliacea*, *Sphenoclea Zeylanica*, *Ludwigia hyssopifoloa*, *Monochoria vaginalis*, *Leptochloa chinensis*, and *Echinochloa colona*. The IMI-herbicides (ONDUTY and KIFIX) effectively controlled weeds at all stages (Table 16). When compared to the untreated check, total weed density was >98% lower at 25 and 55 DAS in the treatments with IMI-herbicides. A standard herbicide program also effectively controlled weeds at 25 and 55 DAS. At 70 DAS, the treatments did not differ in terms of weed density. This may be partly due to the large variability and also to the fact that some new weeds may have begun germinating that would not be competitive with crop.

Similar to their effect on weed density, IMI-herbicides and other standard herbicide programs effectively suppressed the weed biomass (Table 16). IMI-herbicides reduced total weed biomass by 82-99% compared to the untreated check at all stages. The standard herbicide program suppressed weed biomass from 69 to 91% at different stages.

Table 16. Effect of IMI-herbicides on weed density and biomass of natural weed population at 25, 55, and 70 DAS at IRRI HQ during the 2019 WS[1].

Treatment	25 DAS		55 DAS		70 DAS	
	Total weed count (# m^{-2})					
ONDITY 70WG PRE	1	b	6	b	34	a
KIFIX 70WG early POST	1	b	3	b	12	a
Pretilachlor (PRE) fb bispyribac (POST)	10	b	16	ab	49	a
Pyribenzoxim + cyhalofop (Early POST)	3	b	77	ab	112	a
Untreated control	78	a	342	a	100	a
	Total biomass(g m^{-2})					
ONDITY 70WG PRE	1.4	b	5	b	3	b
KIFIX 70WG early POST	1.4	b	1	b	38	b
Pretilachlor (PRE) fb bispyribac (POST)	1.3	b	26	b	40	b
Pyribenzoxim + cyhalofop (Early POST)	0.9	b	59	b	60	b
Untreated control	10.0	a	190	a	215	a

[1] *Within column, means followed by the same letter are not statistically different at 5% level of significance.*

Both of the IMI-herbicides (ONDUTY and KIFIX) completely suppressed (100%) the emergence and growth of *Ischaemum rugosum*, a key problematic weed in wet-DSR in Asia, at both 25 and 55 DAS (Table 17). The standard herbicide-programs used in this study were also found to be effective in controlling *I. rugosum*, suppressing density and biomass by 88-100% at 25 and 55 DAS (Table 17).

Both IMI-herbicides (ONDUTY and KIFIX) completely controlled purple rice (used to simulate their effect on weedy rice) at 55 DAS (Table 18). However, the standard herbicide program used in this study did not affect purple rice emergence and growth. The results suggest that Clearfield technology can be very effective in controlling weedy rice in direct seeding systems.

B) Effect on crop: Both KIFIX and ONDUTY were found safe and did not cause any adverse effect on different plant growth parameters, including crop establishment, plant height, leaf area index, and crop biomass at different stages (data not shown).

C) Carryover effects on non-Clearfield rice: No significant difference in the crop count and biomass of non-Clearfield rice was observed among treatments (Fig. 18 and 19) in the non-Clearfield rice planted at 8 (77 days after ONDUTY application) and 27 days (96 days after ONDUTY application) after termination of the Clearfield rice experiment. This suggests that there was no carryover effect on rice beyond 70 DAS under puddled soil conditions. The results suggest that normal rice varieties can be grown under wet-DSR after a crop of Clearfield rice with an IMI-herbicide-based weed control program has been harvested.

Table 17: Effect of IMI-herbicides on emergence and biomass of *Iscahemum rugosum* (seeded weed) at 25 and 55 DAS at IRRI HQ during the 2019 WS[1].

Treatment	25 DAS		55 DAS		25 DAS		55 DAS	
	Density (# m^{-2})				Biomass (g m^{-2})			
ONDITY 70WG PRE	0	b	0	b	0.0	b	0	b
KIFIX 70WG early POST	0	b	0	b	0.0	b	0	b
Pretilachlor (PRE) fb bispyribac (POST)	6	b	0	b	0.7	b	0	b
Pyribenzoxim + cyhalofop (Early POST)	4	b	1	b	0.2	b	1	b
Untreated control	63	a	25	a	5.7	a	259	a

[1] *Within column, means followed by the same letter are not statistically different at 5% level of significance.*

Table 18. Effect of IMI-herbicides on the emergence and growth of purple rice at 55 DAS at IRRI HQ during 2019 WS[1,2].

Treatment	Emergence (#)		Biomass (g)	
ONDITY 70WG PRE	0	b	0	b
KIFIX 70WG early POST	0	b	0	b
Pretilachlor (PRE) fb bispyribac (POST)	19	a	45	a
Pyribenzoxim + cyhalofop (Early POST)	21	a	68	a
Untreated control	21	a	58	a

[1] *Purple rice was used to simulate the effect of IMI-herbicide on weedy rice*

[2] *Within column, means followed by the same letter are not statistically different at 5% level of significance.*

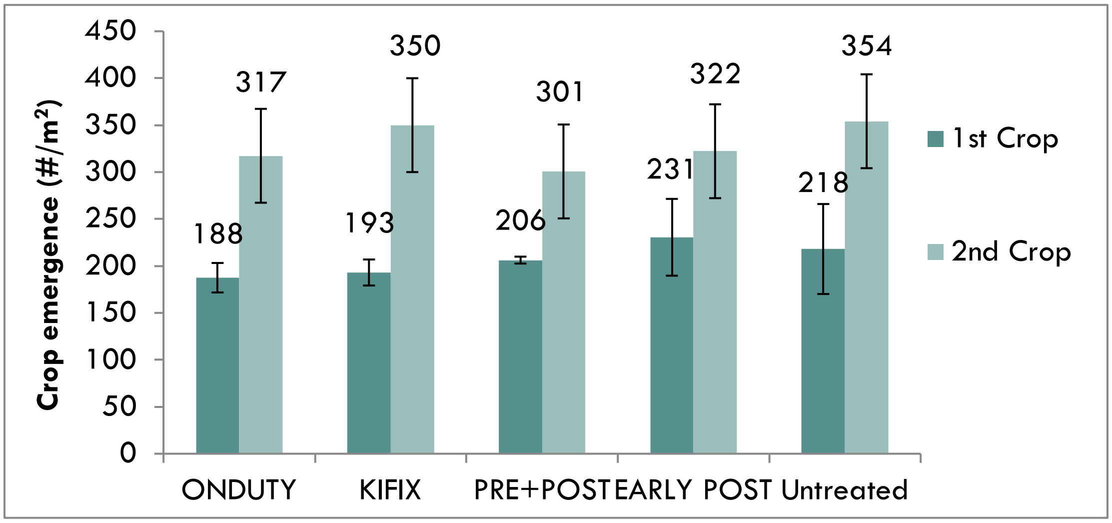


Figure 18. Emergence of the first and second crop of non-Clearfield rice planted at 77 and 96 days after ONDUTY application, respectively, under wet-DSR during the 2019 WS. Treatment effect was non-significant at both timings.

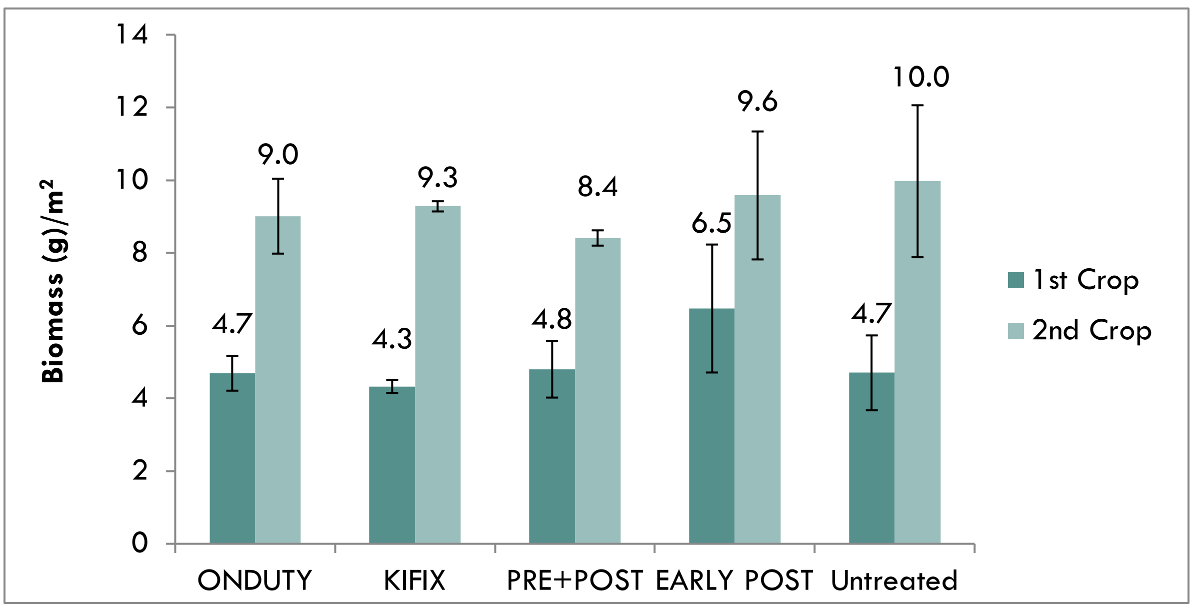


Figure 19. Crop biomass of the first and second crop of non-Clearfield rice planted at 77 and 96 days after ONDUTY application, respectively, under wet-DSR during the 2019 WS. Treatment effect was non-significant at both timings.

Experiment 2: RESPONSE OF NON-CLEARFIELD RICE VARIETIES TO SIMULATED DRIFT OF IMAZAPYR + IMAZAPIC (KIFIX 70%WG)

Treatment:

Factor 1: Application timing (3)

1. Early seedling stage (10 DAS)
2. Tillering stage (35 DAS)
3. 60 DAS

Factor 2: Reduced herbicide rates (5)

1. KIFIX @ 6.25% of 1X rate
2. KIFIX @ 12.5% of 1X rate
3. Untreated check

Plot size: 3 m x 6 m

Method:

Rice cultivar RC-18 was seeded in line using a drum seeder at a seed rate of 30 kg ha^{-1} on August XX, 2019. The experimental design was a factorial randomized complete block design with three replications. Factor 1 consisted of KIFIX applied at reduced rates of 6.25% and 12.5% of the recommended rate for use with Clearfield rice varieties. Factor B consisted of application timing at different rice growth stages: early seedling stage (10 DAS), tillering stage (30 DAS), and at panicle initiation (PI) (60 DAS). KIFIX was applied at a spay volume of 280 L ha^{-1}. The experimental area was kept weed free using pretilachlor with safener as PRE followed by hand weeding. The land preparation, fertilizer, water management, seed treatment/preparation, and pest management was similar to seed rate experiment for wet-DSR (see Table 10 for details).

Results:

The results showed that both KIFIX application rate and time of application significantly affected rice yield, but their interaction was non-significant, suggesting that the application rate effect was not influenced by crop stage (Table 19, p-value). With KIFIX application, irrespective of crop stages, yield was 35% and 54% lower when it was applied at 6.25% and 12.5% of the recommended rate, respectively, compared to no application of KIFIX. Irrespective to application rate, KIFIX application resulted in the highest yield loss when applied at a later stage (60 DAS) than at an early stage (10 DAS). For example, rice yield reduction compared to the non-treated check was 25% when KIFIX was applied at 10 DAS whereas yield reduction increased to 45% and 62% when KIFIX application was applied late at 30 DAS and 60 DAS, respectively. This could be because when KIFIX was applied early, the crop had a longer time to recover from the phytotoxicity whereas when it was applied at later stage, the crop did not have sufficient time to recover, which resulted in higher yield losses. These results suggest that drift from KIFIX application can impose a risk to neighboring farmers growing normal rice cultivars that are not tolerant to IMI-herbicides and that this risk is highest when the crop in the neighboring field is at a later stage of development (around 60 DAS) – close to PI.

Table 19. Effect of simulated KIFIX drift application rate and timing on crop yield during 2019 WS, as percent of the non-treated check at IRRI HQ.

Timing of application	Yield					
	6.25% of recommended		12.5% of recommended		Average (time of application)	
	-----% reduction in yield compared to non-treated check--------					
10 DAS	22		28		25	b[1]
30 DAS	31		60		45	ab
60 DAS	51		73		62	a
Average (KIFIX dose)	35	A[2]	54	B		
Nontreated check[3]	*4.25 t ha⁻¹*					
	----------------*ANOVA (p-value)*----------------					
Time of application (T)	*0.016*					
Dose (D)	*0.047*					
T*D	*NS*					

[1] Means within a column followed by the same lowercase letter were not statistically different according to Tukey HSD test at 5% level of significance.
[2] Means within a row followed by same uppercase letter were not statistically different according to Tukey's HSD test at 5% level of significance.
[3]Actual rice yield (t ha^{-1}) of non-treated check where KIFIX was not applied.

2.4. Effect of Seed Treatment Solutions on Crop Establishment, Yield and Insect-Related Ecosystem Functions in Rice Fields

This experiment was designed to assess the effects of seed treatment and varietal choice on arthropod-related ecosystem processes in rice fields. The goal was to observe two particular ecosystem processes: i) decomposition, since this process is mainly carried out by soil arthropods that may be affected by seed treatments, and ii) herbivory, as seed treatments and varietal choice may affect this process through toxicity (in the case of seed treatment) and resistance (in the case of variety)

Treatment:

Factor 1: Cultivar (2)

- Hybrid
- Inbred

Factor 2: Seed treatment (3)

- Seed treatment 1
- Seed treatment 2
- Seed treatment 3
- No seed treatment (untreated check)

In this study, RC18 was used as an inbred and PBH79 was used as a hybrid

Three seed treatment solutions were tested: Chlorantaniliprole (Lumivia), Imidacloprid (Gaucho), and Isotianil (Routine Start)

Method:

The field was puddled and dry seeds of both varieties were then seeded in line and covered with dry soil. The following observations were made:

1. Decomposition rate: Ten grams of rice straw in mesh bags that allow for soil arthropod movement was buried in each plot and given 30 days to decompose. After 30 days, the mesh bags were retrieved, the soil was cleaned from them, and the remaining straw was weighed. The difference between the initial and final straw weight was used as an indicator of the decomposition rate, which in turn is an indicator of the impact of the seed treatment solution on soil biodiversity, if any.

2. Plant injury: Ten quadrants were chosen at random for each plot. Plant injuries from mole crickets, stemborers, whorl maggots, leaf folders, hopperburns, and tungros were assessed five times in one season (at 2, 4, 6, 10, and12 weeks after sowing). The rate of injury from each insect was used as an indicator of herbivory. The ten quadrants on each plot were randomized for each sampling date.

3. Insect abundance: During the same sampling event, insect samples were taken by sweep-netting (~20 sweeps diagonally across the plot). The abundance of herbivorous insects (listed above) and select natural enemies were quantified for each sampling date.

4. Yield and yield attributes

Results:

Decomposition rate: There was no statistically significant effect of seed treatment on the decomposition rate of rice straw in this experiment (Figure 20). These results indicate that soil biological activity (soil microflora or soil arthropods) was the same and was unaffected by the seed treatments.

Plant injury and insect abundance: Whorl Maggots were the only defoliators present in the early stages of the crop. At 27 DAS (Table 20), whorl maggot incidence in the untreated check and seed treatment 3 (the fungicide-based seed treatment) had significantly higher incidence of injuries compared to insecticide-based seed treatment solutions (seed treatments 1 and 2). The data also suggest that hybrid rice is significantly more susceptible to defoliators than inbred varieties, which aligned with previous studies. However, in the later stages of the crop at 40 DAS (Table 21), whorl maggot incidence was not significant in the treatment solutions. This result suggests that seed treatment solutions is only effective in the early stages of these crops. In the later stages, defoliator incidence was affected by variety, with higher infestation observed in hybrids than in inbreds.

Yield: All seed-treated crops had significantly higher yields compared to the non-treated check. Among varieties, the hybrid produced a 28% (1.0 t ha^{-1}) higher yield than the inbred variety (Table 22). Although the incidence of pests was very low, the seed treatment had a positive impact on rice yield, which suggests that these solutions may have had some growth-promoting effects on the crop that may have positively impacted the yield.

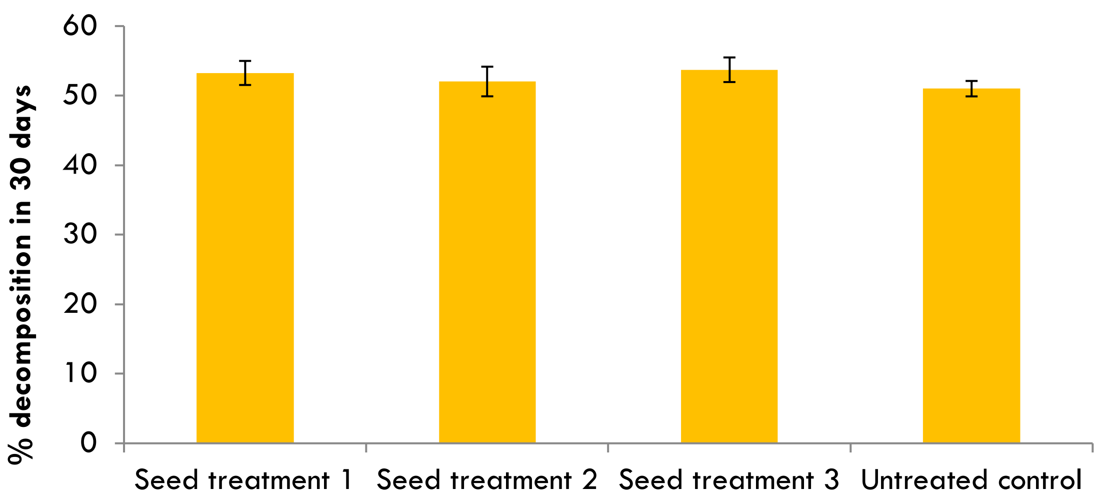


Figure 20. Decomposition of rice straw (%) under different seed treatment solutions in first 30 days.

Table 20. Whorl Maggot incidence (%) as affected by seed treatment and varietal choice at 27 DAS

Seed treatment	Variety		Average.
	Hybrid	Inbred	
Seed treatment 1	9.97	3.95	6.96 b
Seed treatment 2	8.02	1.48	4.75 c
Seed treatment 3	15.48	14.36	14.92 a
Untreated control	24.99	17.10	21.04 a
Average	14.61 A	9.22 B	
	ANOVA		
Variety (V)	0.0120*		
Seed treatment (ST)	0.0001*		
V x ST	NS		

[1] Means within a column followed by the same lowercase letter were not statistically different according to Tukey HSD test at 5% significance.
[2] Means within a row followed by the same uppercase letter were not statistically different according to Tukey's HSD test at 5% level of significance.

Table 21. Whorl Maggot incidence (%) as affected by seed treatment and varietal choice at 40 DAS

Seed treatment	Variety		Average
	Hybrid	Inbred	
Seed treatment 1	31.10	10.20	20.65
Seed treatment 2	34.46	21.00	27.73
Seed treatment 3	27.94	18.43	27.94
Untreated control	34.90	18.84	26.47
Average	31.90 A	17.12 B	
	ANOVA		
Variety (V)	0.0069 *		
Seed treatment (ST)	NS		
V x ST	NS		

[1] Means within a column followed by the same lowercase letter were not statistically different according to Tukey HSD test at 5% significance.

Table 22. Rice grain yields of hybrid and inbred varieties treated with different seed treatment solutions

Seed treatment	Variety				Average
	Hybrid		Inbred		
Seed treatment 1	4.09		3.26		3.68 ab
Seed treatment 2	4.52		3.82		4.17 a
Seed treatment 3	4.91		3.76		4.33 a
Untreated control	3.81		2.63		3.22 b
Average	4.33	A	3.37	B	
	ANOVA (p-value)				
Variety (V)	0.0018*				
Seed treatment (ST)	0.0301*				
V x ST	NS				

[1] Means within a column followed by the same lowercase letter were not statistically different according to Tukey HSD test at 5% significance.
[2] Means within a row followed by the same uppercase letter were not statistically different according to Tukey's HSD test at 5% level of significance.

2.5. Optimizing and Evaluating Drip Irrigation In Dry-DSR

Rationale: As water becomes scarce and expensive in Asia, the conventional practice of PTR, which requires large quantities of water (approximately 2500 liters to produce 1 kg of rough rice), together with the highly inefficient existing systems of irrigation water management, contribute to the grim future scenario projected for water availability in agriculture. The future demand for water in Asia warrants exploration of alternative rice production methods and irrigation water management practices that make more efficient use of water resources. Dry-DSR is one such alternative rice establishment method since it requires less irrigation water than PTR. In addition, micro-irrigation approaches, such as drip irrigation (surface or sub-surface), may offer opportunities to further reduce the amount of irrigation water used in dry-DSR by reducing non-productive water losses. Additionally, these practices also reduce methane emissions compared to continuously flooding paddy fields.

This study was planned and developed to create scientifically sound irrigation criteria for optimizing drip irrigation systems in DSR. The focus is to achieve higher productivity, profitability, and resource efficiency by optimizing agronomic efficiency through the use of drip irrigation. Our aim is to provide the integrated knowledge required by researchers, crop advisors, irrigation managers and decision-makers to assess and better manage future rice-based production systems with drip irrigation.

Overall objectives:

1. To estimate irrigation water savings with drip irrigation compared to flood irrigation systems
2. To evaluate the impact of drip and fertigation on yield and water productivity
3. To assess the effect of drip irrigation systems on other parameters, including environmental impact (greenhouse gas emission) and weed population dynamics

The drip irrigation system (Jain Irrigation Systems Ltd.) was installed in the in E-block of the IRRI HQ Research Farm and covers around 4, 100 m^2 experiment field (see inset below). It is driven by a 2HP submersible pump, which is DC-powered by 6-pc solar panels (300 watts/panel). The assumed water discharge capacity of the system is 7,500 liters/hour (45,000 liters/6 hours; i.e., 1 day) under full potential (high solar radiation and zero to minimum cloud cover). The drip irrigation system was installed in April 2019, and it is vital for researchers at IRRI to understand the system before they can successfully use it for cropping experiments with agronomic measurements. An exercise to determine the actual water discharge from the drip irrigation system at varying points across the whole experiment area as affected by solar radiation (time of day for irrigation application) was conducted before 2019 wet-season rice crop was established. The first rice crop was also established and evaluated. The following were specific objectives for 2019:

Specific objectives for 2019:

1. Understanding and optimizing the operation of the solar-powered drip irrigation system installed at the DSRC site at IRRI HQ
2. Determining the effect of the two-drip irrigation system (surface and subsurface) on yield and water productivity using 70%, 100% and 130% of crop water demand as an irrigation scheduling threshold

Inset: Drip irrigation installation set-up at IRRI HQ

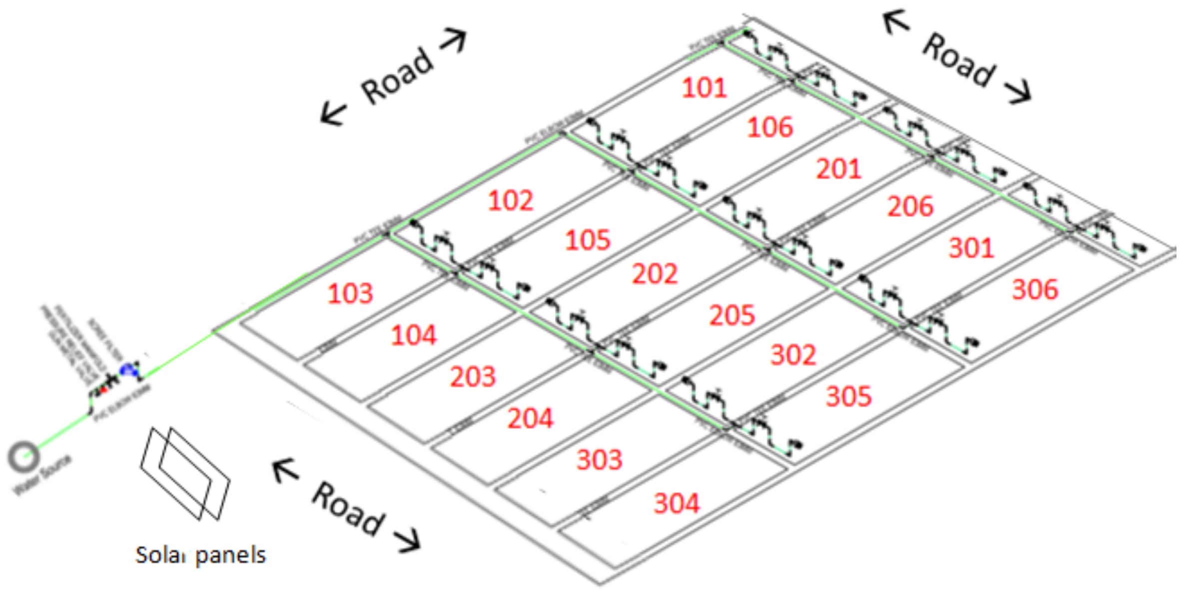
Objective #1. Understanding and optimizing the operation of the solar-powered drip irrigation system installed at the DSRC site at IRRI HQ

The final set-up is shown in the illustration below (see inset). The system is designed to discharge 2 liters per hour (L/hr) or 2000 mL per hour (mL/hr) from each dripper. Each plot (25 m x 9 m; 728 m^2) has 15 driplines with 63 drippers each, which brings the total number of drippers to 945 per plot. Assuming 2L/hr per dripper, the system can discharge 1,890 L/hr per plot (2 L/hr x 945 drippers/plot) or 1.89 m^3/hour or 2.59 mm of depth per plot. To understand how the drip system installed at IRRI works, several factors that may affect the water discharge were explored. Red cross: factors affecting water discharge; blue cross: measurement points for water discharge.

Four short-term experiments were conducted to understand the different factors affecting water discharge by drippers with the goal of optimizing the operation of the solar-powered drip irrigation system. These experiments are explained below with key findings.

Experiment 1: UNDERSTANDING CAPACITY OF THE SYSTEM TO IRRIGATE A NUMBER OF PLOTS WITH CONSISTENT FLOW PER IRRIGATION SHIFT

First, we checked how much water was discharged from the dripper when running the irrigation simultaneously for 6, 5, and 4 plots per shift. Apparently, from the measurements (Fig. 21), the most reliable number of plots that could be irrigated per shift was found to be 4 (mean at 2065 mL/hr; SD ±139 mL/hr; ranging from 1620-2280 mL/hr). When five plots per shift were irrigated simultaneously, the system also delivered close to 2 L/hr (mean at 1935 mL/hr; SD ±254 mL/hr; ranging from 830-2230 mL/hr). However, when the system was run with 6 plots simultaneously, the discharge was reduced (mean at 1492 mL/hr; SD ±152 mL/hr; ranging from 1100-1660 mL/hr). These results suggest that with the current system, 4 plots can be irrigated simultaneously with acceptable accuracy. To minimize the risk, we irrigated three plots at a time to get relatively robust measurements during the 2019 wet-season experiment, as well as for other short-term experiments on optimization of drip operation.



Inset: Final drip irrigation set-up with layout

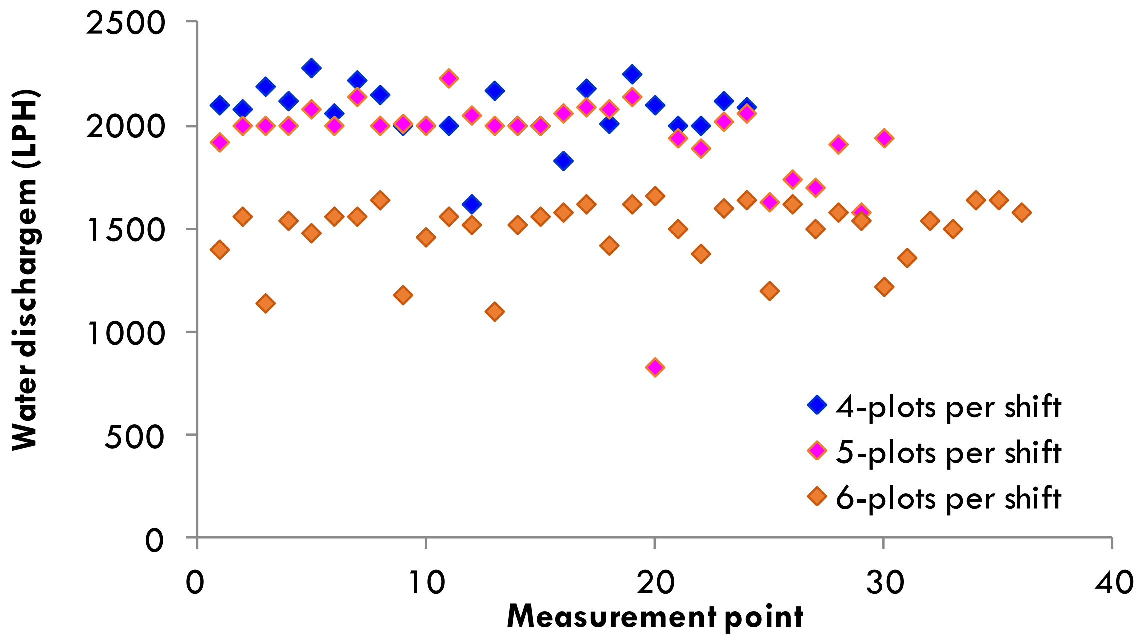


Figure 21. Water discharge from each dripper when irrigation was applied in 4, 5, and 6 plots simultaneously per shift.

Experiment 2: UNDERSTANDING THE EFFECT OF SOLAR RADIATION (TIME OF DAY) ON THE WATER DISCHARGE BY THE SOLAR POWERED DRIP SYSTEM

Three trials were performed to measure the water discharge from drippers in 4 plots at different locations (plots and spots within the plots) covering the entire irrigation system (Fig. 22). Irrigation runs were conducted at different times during the day: 7-8 am, 10-11 am, 12 noon-1pm, and 2-3 pm. The highest discharge was observed during the time windows of 10-11am (mean at 2031 mL/hr, SD ±-341 mL/hr) and 12 noon-1pm (mean at 2119 mL/hr, SD ±373 mL/hr). The lowest discharge was observed in the 7-8 am window (mean at 1827 mL/hr, SD ± 296 mL/hr), followed by the 2-3 pm window (mean at 1972 mL/hr, SD ± 336 mL/hr). These results suggest that the most reliable time for irrigation using the solar-powered drip system would be from 8 am to 2 pm based on a 2 L/hr rate.

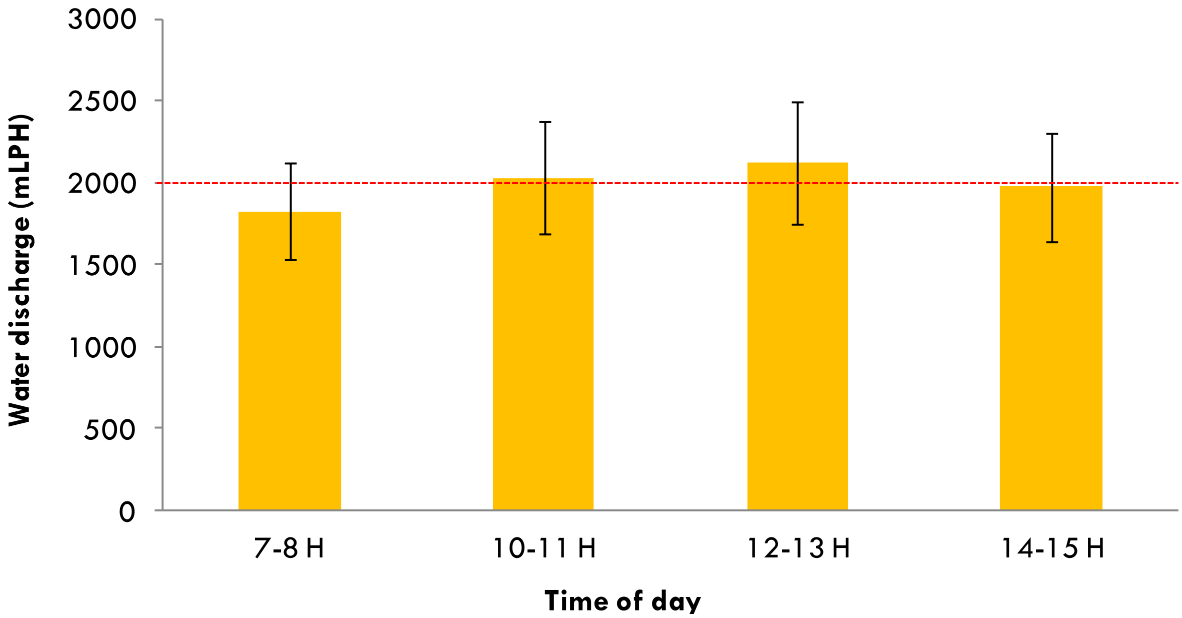


Figure 22. Water discharge per dripper of 4 plots at different locations (plots and spots within the plots) covering the entire system, taken at different time windows

Experiment 3: UNDERSTANDING THE EFFECT OF THE DISTANCE OF PLOTS AND DRIPPERS WITHIN A PLOT FROM THE WATER SOURCE ON WATER DISCHARGE

Water discharge from drippers of strategically located plots those closer and farther from the water source (Plots 101, 103, 301, and 303; see actual set up) – was measured to determine the amount of variation that can be expected when irrigating 4 plots per shift. Discharge from drippers located at six locations (A1, A2, B1, B2, C1, and C2) within each plot (Fig. 23) was also measured separately. Drippers denoted 1 are closer to the lateral source than those denoted 2, which are located on the opposite end of the driplines.

Based on the results (Fig. 24), drippers in the plots discharged an average of 1917 mL/hr (SD ±89, ranging from 1831-2030 mL/hr) of water. This is very close to the 2000 mL/hr or 2 L/hr that the system is designed to deliver (96% delivery). We also observed that there was a tendency towards lower discharge (with higher variability) with increased distance from the water source.

Figure 25 shows the water discharge at different points within each plot when we checked how irrigation was being distributed. The water discharge on the 'A side' (mean 1903 mL/hr; SD ±192 mL/hr) was more variable than either the 'B side' (mean 1800 mL/hr; SD ±3 mL/hr) or the 'C side' (mean 2046 mL/hr; SD ±26 mL/hr). Apparently, the 'B driplines,' located in the middle of the plot, are prone to lower discharge compared to the driplines along the edges of the plot.

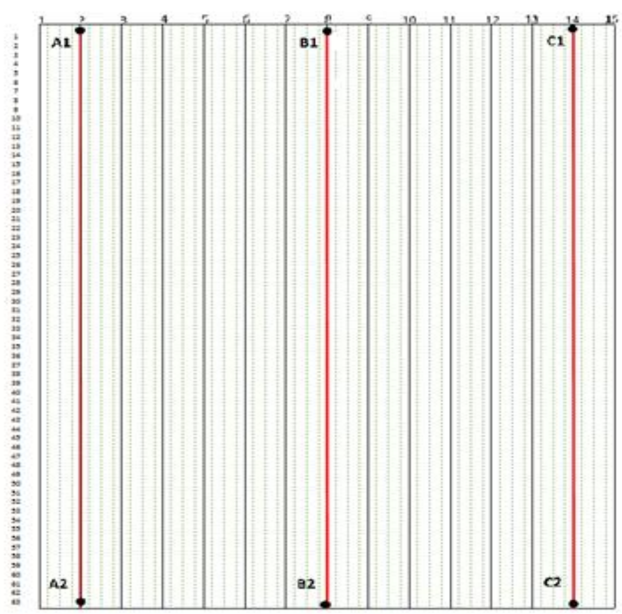


Figure 23. Drip Irrigation set-up in each plot, showing the 15 driplines (gray and red lines) with 63 drippers. The green lines indicate plant rows sown ~20 cm apart. Three plant rows fit between 2 drip lines with the two outer plant rows closer to the drip lines(10 cm) and the third middle row farther from drip lines (30 cm). Points A1, A2, B1, B2, C1, and C2 were the locations where water discharge was measured.

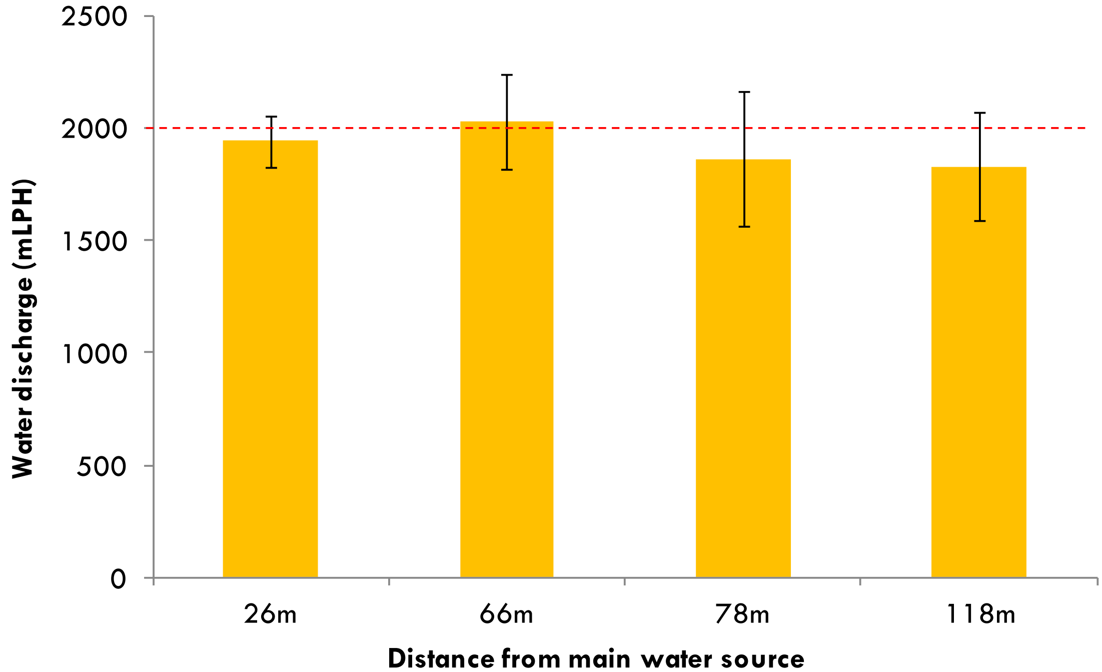


Figure 24. Water discharge per dripper in 4 plots located at different distances from the water source. The main water source refers to the flowmeter installed at the start of the main line (see actual set-up illustration).

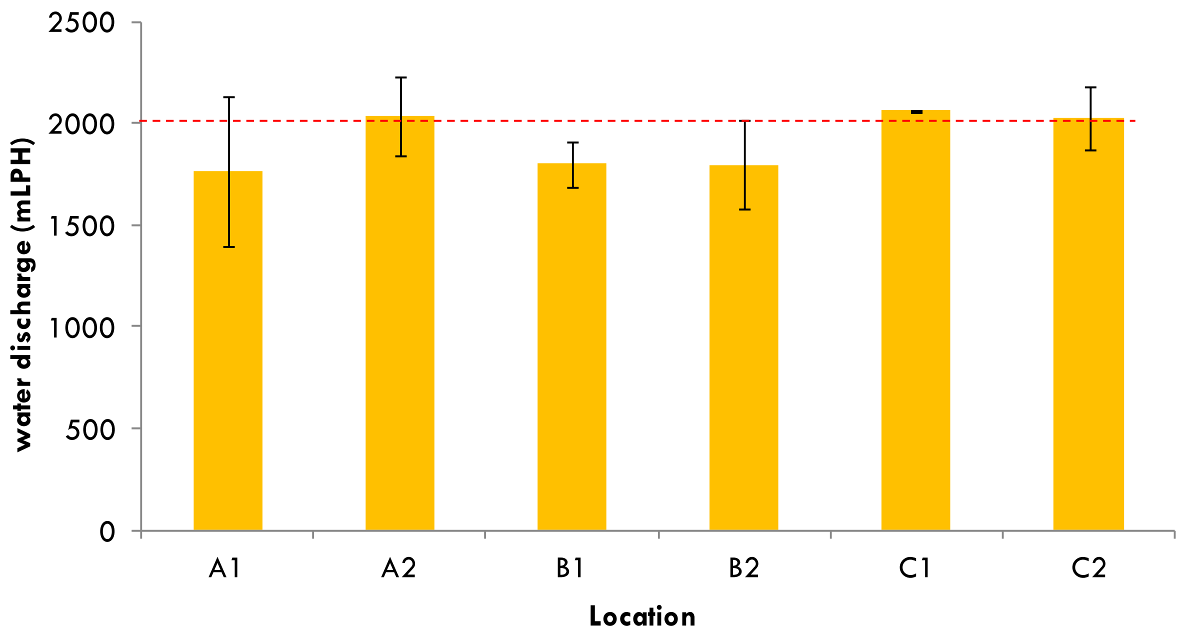


Figure 25. Water discharge per dripper at different locations within the 4 plots covering the entire irrigation system. Note that subscript *1* indicates a location ~120 cm from the lateral line, and subscript *2* indicates a location ~2400cm from the lateral line. The '*A drippers*' are located closest to the main line, followed by '*B drippers,*' and the '*C drippers.*'

Experiment 4: COMPARING WATER DISCHARGED PER DRIPPER AND FLOWMETER MEASUREMENTS

To measure the exact amount of irrigation water applied to the experimental plots, a flowmeter was installed at the gate of the drip system. We then checked how the flowmeter measurement relates to the volume measured based on the water discharged by each dripper (Fig. 26). Apparently, the average volume recorded using the flowmeter and the volume of dripper output are almost 1:1 (6.99 m^3:6.90 m^3). The inline pressure was monitored throughout the entire cycle; however, this measurement did not correlate well with the volume discharge.

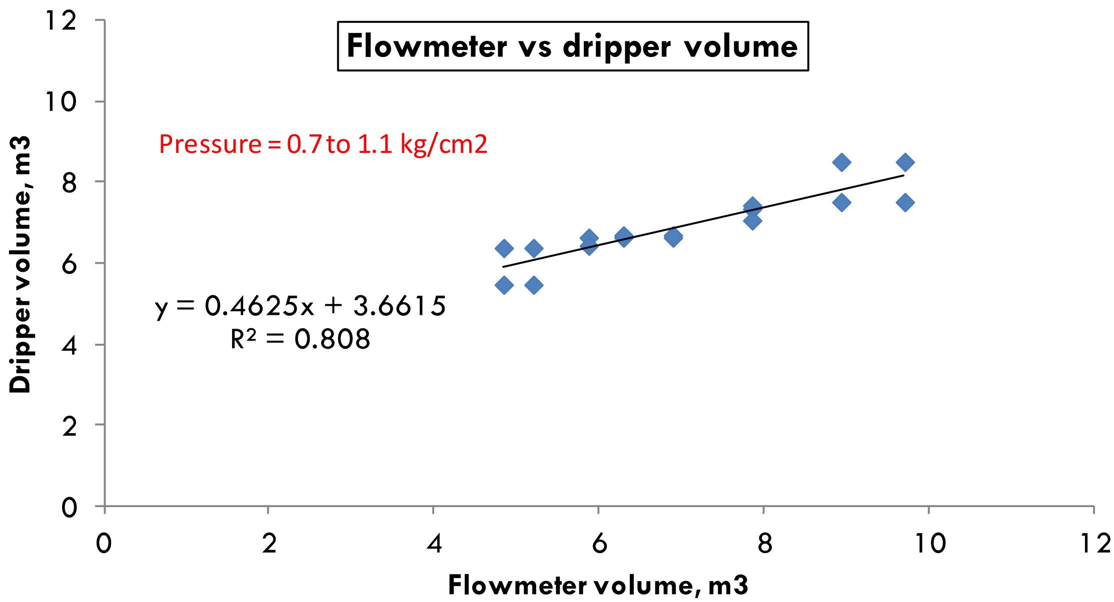


Figure 26. Volume of water discharge using flowmeter and output measured from drippers. Volumes were calculated for each irrigation shift on 3 plots.

Objective #2. To determine the effect of the two-drip irrigation system (surface and subsurface) on yield and water productivity

Treatments:

Factor 1: Type of Drip Irrigation (2 levels)

- Surface drip irrigation system (S1)
- Sub-surface drip irrigation system (S2)

Factor 2: Irrigation scheduling threshold (3 levels)

- Irrigation scheduling at 70% crop demand (I1)
- Irrigation scheduling at 100% crop demand (I2)
- Irrigation scheduling at 130% crop demand (I3)

Treatment combinations:

T4 = Surface drip irrigation with irrigation scheduling at 70% crop demand (S1I1)

T5 = Surface drip irrigation with irrigation scheduling at 100% crop demand (S1I2)

T6 = Surface drip irrigation with irrigation scheduling at 130% crop demand (S1I3)

T7 = Sub-surface drip irrigation with irrigation scheduling at 70% crop demand (S2I1)

T8 = Sub-surface drip irrigation with irrigation scheduling at 100% crop demand (S2I2)

T9 = Sub-surface drip irrigation with irrigation scheduling at 130% crop demand (S1I3)

Note that *T1, T2, and T3 were puddled transplanted rice (PTR), wet direct-seeded rice (wet-DSR), and dry direct-seeded rice (dry-DSR), respectively, with flood irrigation systems (conventional irrigation method). These treatments were shared with the cropping system experiment. The seeding date, cultivar, and other agronomic practices were kept similar between the drip irrigation and the cropping system experiments.*

Plot size: *9 m x 25 m (225 m^2)*

Total experimental area: *0.6 ha*

Replications: *3*

Design: *Randomized complete block*

Materials and Methods:

The crop management practices used in the drip irrigation experiment during cropping season #1 (2019 WS) are given below:

Practice	Detail
Land preparation	The field was tilled dry and leveled using a small tractor. Tillage was kept shallow (5 cm) while avoiding the drip lines.
Seed preparation and seed treatment	Dry seeds were used. Seeds were not treated with an insecticide or fungicide.
Sowing date	July 6, 2018
Variety	Mestizo 77 or NSIC 2016 Rc 454H (IR81958H)
Fertilizer (N: P_2O_5: K_2O)	120:40:20 kg ha^{-1}
Weed management	Pre-emergence (Pretilachlor) + 1-2 hand weeding
Pest management	No insecticide or fungicide applied.
Crop establishment*	The seeds were line sown using an MP seeder with 20-cm row spacing. Three plant rows were grown along with the 60-cm space between drip lines.
Irrigation	To ensure optimum germination and seedling establishment, the rice was irrigated every day by returning 130% of crop water demand up to 28 DAS. Irrigation scheduling based on 70%, 100%, and 130% of crop water demand was applied from 29 DAS until crop maturity. After rain events, succeeding irrigation was applied when 10 kPa soil moisture tension (SMT) at 15 cm soil depth was reached (monitored using tensiometers).

** Gap filling along plant rows continued until July 26 2019.*

The following data were collected: i) irrigation water and total water input, and ii) yield and yield attributes. For yield estimation, a total area of 16 m2 from each plot was harvested from two locations of 8 m2 each, and the mean yield of both locations was considered the plot yield. Yield components were also determined from four locations (0.8 m^3) surrounding each grain yield area. Plants were destructively sampled at physiological maturity. Grains were separated from straw in all samples. The yield components (number of panicles, weight of spikelets on each panicle, number of filled and unfilled spikelets on each panicle, and the weight of 1000 filled grains from each panicle) were determined for each grain yield area.

Results and discussion:

Yield and yield attributes: Rice grain yield did not differ between the surface and sub-surface drip methods (Fig. 27). Yield was also unaffected by the three irrigation scheduling thresholds at 70%, 100%, and 130% of crop demand.

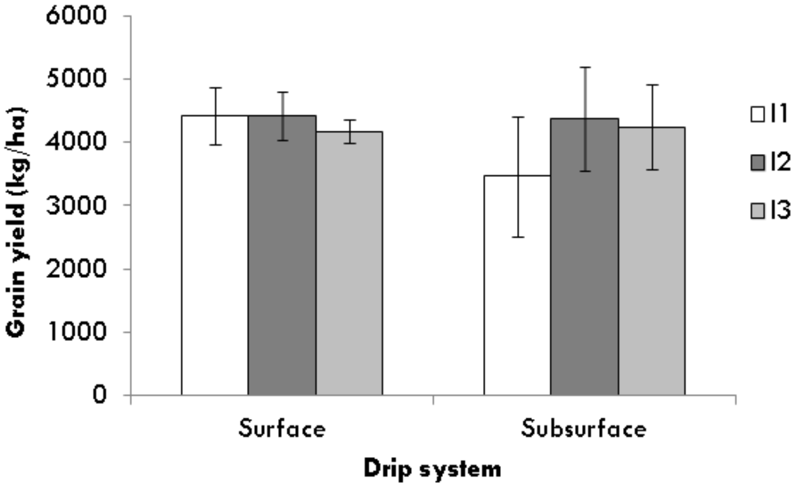


Figure 27. Grain yield (kg/ha) from surface and subsurface drip using irrigation scheduling threshold at 70%, 100%, and 130% of crop demand. Bars indicate SD.

Generally, the yield components were slightly higher with the surface drip than with the subsurface system, but these results were not statistically significant (Fig. 28). Although not significant, there were more panicles (~224 panicles m^{-2}) and heavier grain weight (24 g/1000 grains) in the rice grown with the surface drip than with the sub-surface drip (Fig. 28 A and D). The number of spikelets on each panicle was 8% lower in surface drip compared to sub-surface drip; however, the surface drip had slightly higher filling % (74%) (Fig. 28 B and C). Since the same rice variety and nutrient management were used in both surface and subsurface drip treatments, the difference was mainly attributed to the drip irrigation system, especially because I_{70}, I_{100}, and I_{130} treatments had the same irrigation run time regardless of whether the surface or subsurface system was used.

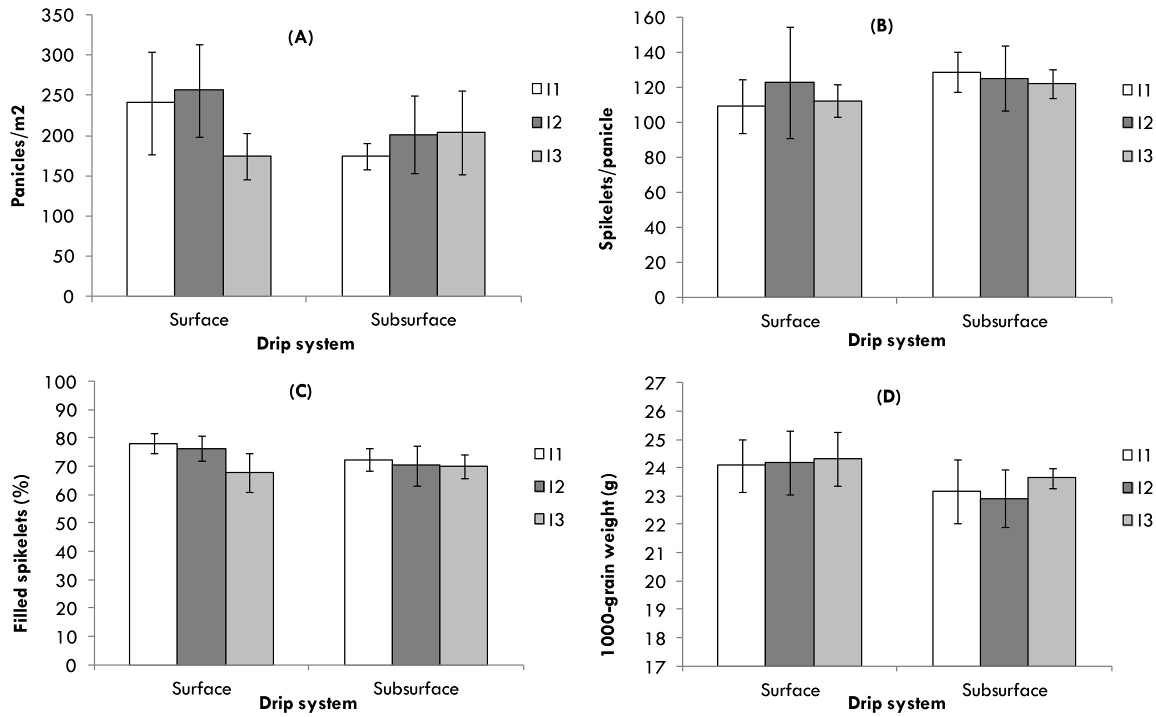


Figure 28. Yield components of the grain yields for surface and subsurface drip irrigation treatments using 70%, 100%, and 130% of crop water demand as a threshold. Bars indicate SD.

Water input: This kept the drip irrigation to only 25 applications for the ~115-day season. Irrigation water input to I_{70}, I_{100}, and I_{130} using surface drip was 110, 145, and 176 mm/plot, respectively, which was 11% more water than the subsurface drip (Fig. 29). There was ~582 mm of rainfall during the entire season, and this was well distributed with 66 events over the cropping season (Fig. 30). Apparently, despite running the S1 (surface drip) and S2 (sub-surface drip) irrigation treatments for the same amount of time, the water coming out of the subsurface drip system was impeded by some resistance causing lower volume discharge. This may be due to the swelling clay properties of the soil at the experiment site, which may have caused the differences. However, due to the well-distributed rainfall during the season, the drip irrigation input was minimal and resulted in very high irrigation water productivity of DSR, ranging from ~2 to 4 kg m^{-3} (average 3.15 k kg m^{-3}). Total water productivity (rainfall + irrigation water) ranged from 0.52 to 0.71 kg m^{-3} (average 0.57 kg m^{-3}). In comparison, the puddled transplanted rice with continuous flooding irrigation method only had ~0.36 kg m^{-3} irrigation water productivity, while ~0.25 kg m^{-3} for total water productivity.

Conclusion and next steps:

Because the rainfall was well distributed throughout the season, it was difficult to conclusively determine causes and effects. This was made more challenging because the PTR treatment was located a bit far from the drip irrigated plots, which made comparisons difficult. In the upcoming dry season, additional plots will be installed next to the drip plots to make comparisons more realistic and minimize variables affecting soil moisture and irrigation water flow

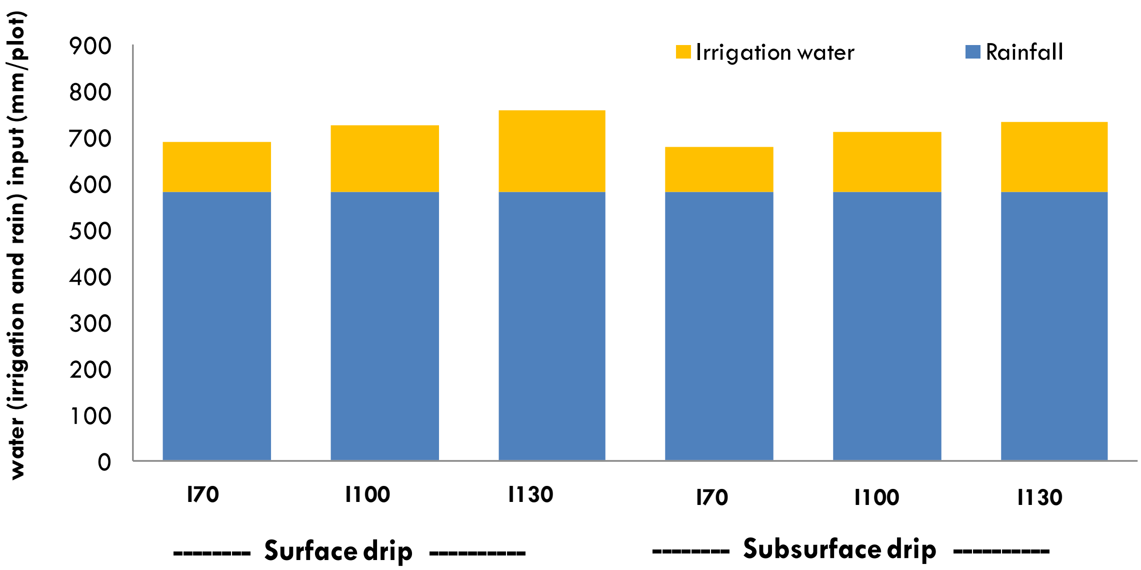


Figure 30. Seasonal irrigation and total water input per plot (225 m^2 area) during the 2019 wet season at IRRI HQ.

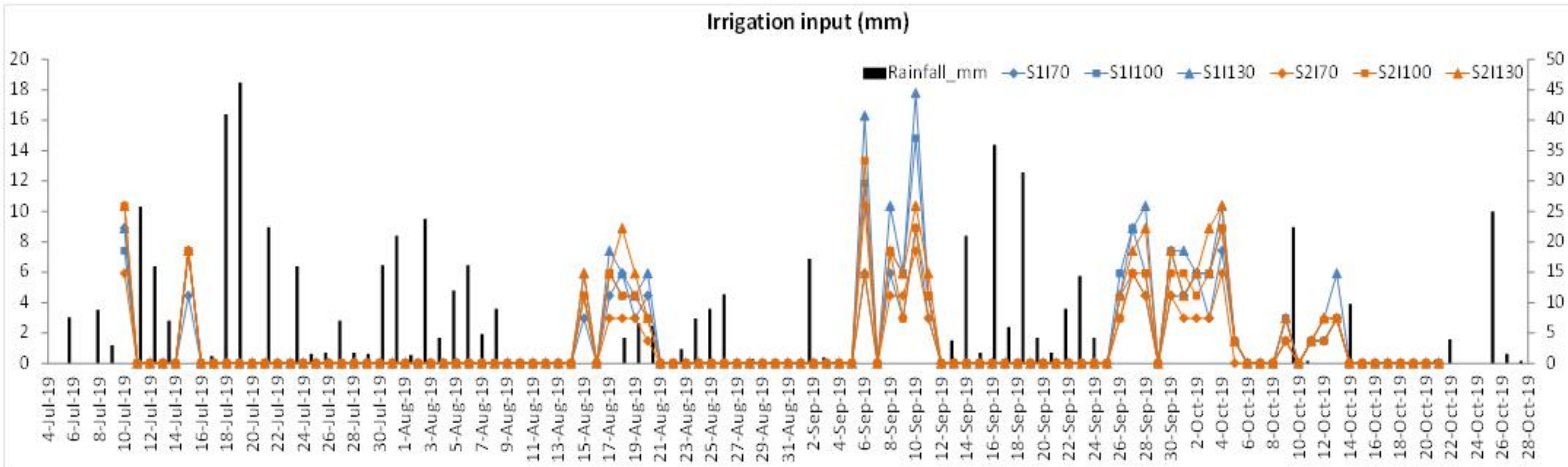


Figure 30. Rainfall distribution and frequency of drip irrigation throughout the cropping season. Date is on the x-axis, amount of irrigation water is on the y-axis, and amount of rainfall is on the z-axis. Black arrows = fertilizer application; red arrows = soil tension threshold of 10 kPa reached.

2.6. Iron Coating of Rice Seed

Rationale: In many parts of Asia, a wet-DSR practice in which pre-germinated seeds are broadcast-seeded in puddled soil has been widely adopted. While the method is faster and requires less labor than transplanting, wet-DSR often requires that fields first be drained to ensure that seeds can anchor on the ground rather than floating away in the water. Unfortunately, draining wastes water, nutrients, and fertile soil clay minerals; it also stimulates the growth of weeds and weedy rice. Iron coating of seeds can facilitate water seeding and eliminate the need for forced drainage since iron coating reduces seed drift under flooded conditions and ensures good establishment. Water seeding may also minimize weed problems, a major adoption constraint in DSR systems. It has been reported that iron coating of seeds also reduces the occurrence of seed-borne diseases and minimizes the incidence of birds eating the seeds. The iron-coating technology used in this experiment was developed and tested in Japan, but its performance has not been evaluated in tropical environments.

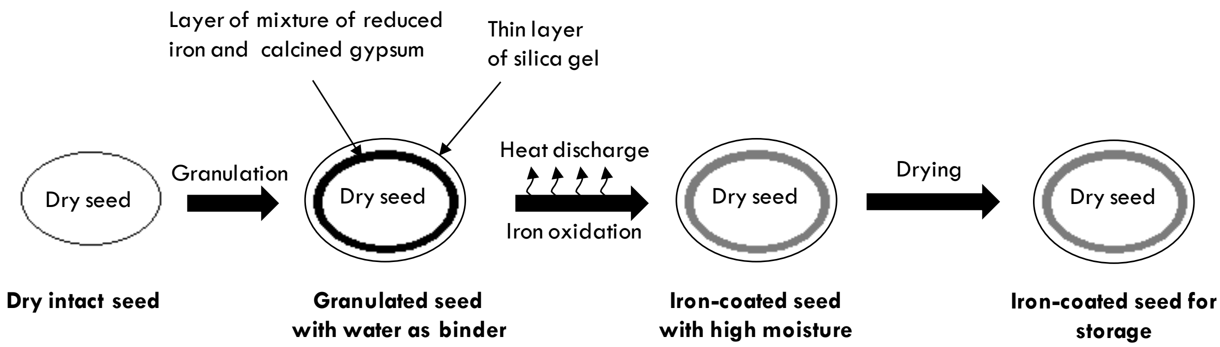
Study 1: DEVELOPING PROTOCOLS FOR PREPARATION OF IRON-COATED RICE SEEDS (MANUAL METHOD FOR SMALLHOLDERS AND MECHANICAL METHOD FOR COMMERCIAL LEVEL SEEDING COATING)

Materials required for iron coating of seed:

1. Konabijin®, which is a combination of reduced Fe powder and calcined gypsum. Konabijin® is a registered trademark of JFE Steel Corporation.
2. Silica gel. The silica gel suitable for preparing Fe-coated seeds has been commercialized (Fuji Silysia Chemical Ltd., Aichi, Japan). The amount of silica gel needed is 0.015 kg kg^{-1} of the seed dry weight.

Iron-coating ratios: The amount of iron used to coat the seed is referred as the iron-coating ratio. This is expressed as weight of the reduced iron powder to the weight of the seeds. The ratio can vary from 0 to 1 or even up to 4. A ratio of 0.5 is commonly used for water seeding. An Fe-coating ratio of 0.5 is also suggested to reduce the damage caused by birds. However, to avoid seed drift, an even lower ratio, in the range of 0.1 to 0.25, can be used.

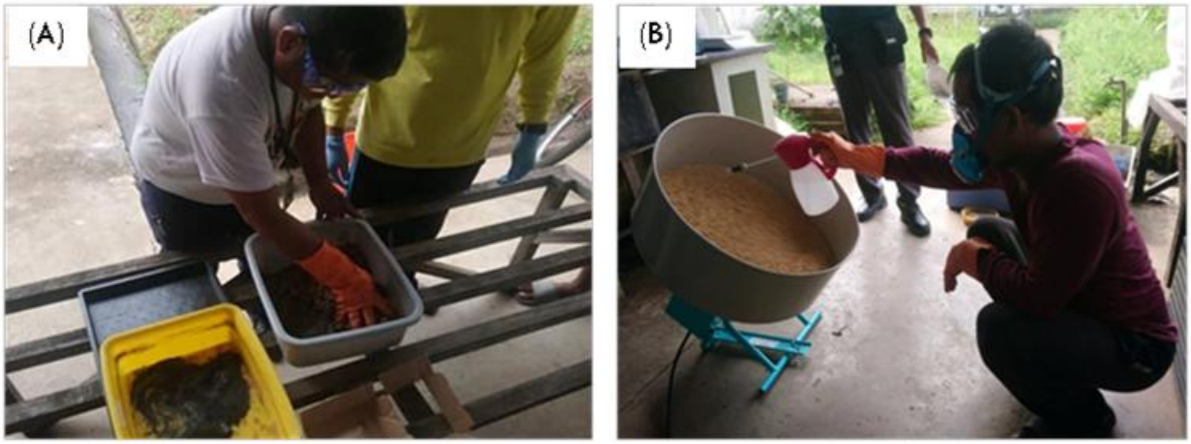
<u>Steps in iron coating of dry rice seed</u>: There are three steps involved in iron coating of rice seeds: (1) granulation of dry seed with Konabijin® followed by surface coverage with silica gel; (2) oxidation of iron on the seed with simultaneous discharge of heat, and (3) drying the seeds (see inset below). These steps are explained below (adapted from Yamauchi 2017).



Inset: Steps in iron coating of rice seeds (Adapted from Yamauchi 2017)

Step 1 (Granulation): In this step, seeds are first covered with an inner layer of the Konabijin® mixture (a combination of reduced iron powder and calcined gypsum) followed by an outer layer of silica gel (as shown in the inset above). This can be achieved manually by individual farmers coating small quantities of seed or using a granulator or concrete mixture for commercial level of seed coating. The seed is first poured into trays or a concrete mixer (granulator) (see inset below). The seed is then sprayed with water and rolled around in the mixer/granulator to allow the Konabijin® mixture to adhere to the seed surface. The amount of water that needs to be sprayed ranges from 0.12 to 0.27 kg per kg of Fe powder. After spraying water on the seeds, cover the seed with Konabijin® mixture. To mix the seed in the trays, divide the seed into three parts and mix evenly and thoroughly by hand. Mechanical mixing of large quantities of seed is done in a granulator/mixer. After covering the seeds with reduced iron powder and calcined gypsum, silica gel is poured onto the seeds, and the seeds are mixed evenly to wrap the seed surfaces with silica.

Note: *seeds covered with a mixture of reduced powder and calcined gypsum (Konabijin®) tend to stick together, forming hard blocks during iron oxidation. To prevent this, the surface of the granulated seed is covered with silica gel at a rate of 0.015 of the iron powder rate.*



Inset : Manual coating of rice seeds (A) and mechanical coating using a granulator or seed mixer (B).

Step 2 (Iron oxidation and discharge of heat): After coating the surface of the seeds with reduced Fe powder (Step 1), the iron must then be oxidized. During iron oxidation, heat is generated. Because the seeds must be kept below 40°C to maintain viability, it is therefore important to discharge or dissipate the heat generated during the oxidation process to avoid killing the seeds. The amount of heat generated and discharged depends on the seed container shape, the properties of the reduced iron powder, the amount of moisture/water in the granulated seeds, and the ambient weather conditions of the work place (temperature, humidity, and wind speed). Heat generation is low if the iron-coating ratio is low.

To discharge the heat, spread the granulated seeds on a platform to expose them to air. We used nursery boxes and spread 1 kg seeds per box (see inset below). These trays are commonly used for raising rice seedlings for machine transplanting across Asia, therefore the nursery boxes can provide a good reference for farmers to use when discharging heat during the oxidation process.

Inset: 6
Nursery boxes used for spreading granulated seeds for iron oxidation and discharge of heat generated during

Note: The reduced Fe powder on the seeds surface must be oxidized, during which heat is generated. The heat should be discharged so that seed temperature is below 40° C to maintain seed viability.

The oxidation reaction (which generates heat) will slow as the granulated seeds lose water/moisture through evaporation. Spraying water on the granulated seeds spread in the nursery tray boxes is recommended after one or two days, in order to restart oxidation and discharge further heat.

Note: if the coated seeds are not spread to discharge the heat and are packed in a container, the temperature will gradually increase and it can peak as high as 60 to 80° C within few hours. This heat can adversely affect the viability of the seeds. Based on our germination experiment, when the heat from the coated seeds was not properly discharged and seeds were packed in a container, germination of the coated seed was reduced by 34%. However, when heat is discharged as explained in step 2, the germination of iron-coated seeds and non-coated seeds were similar.

Step 3 (Drying): Although the surface of the granulated seeds will become brown and dried quickly, a variable amount of moisture will remain under the coating layer (see inset below). Therefore, the seeds need to be air-dried for 4 to 7 days before they are used for seeding or stored. Before storing the seeds in the plastic bags, their water content should be below 13% to avoid the temperature increasing to over 40 C.

Inset : Dry non-coated (left) and iron-coated dry seeds of rice (right)

Study 2: EVALUATING THE PERFORMANCE OF IRON-COATED SEED TECHNOLOGY FOR WET SEEDING AND WATER SEEDING UNDER PHILIPPINE CONDITIONS

Objectives:

- To evaluate the performance of Fe-coated seed technology in tropical wet and dry seasons using wet-DSR and water seeding under puddled conditions in tropical environments
- To determine the optimal Fe coating rates for the tropical rice environment for water and wet-DSR
- To determine the effect of seeding rate of Fe-coated seeds on crop establishment and yields in a tropical environment for wet-DSR under puddled conditions.

Treatments:

Factor1: Coating (4)

1. No coating (dry, intact seed)
2. 25 % Fe-coated seeds
3. 50% Fe-coated seeds
4. Pre-germinated seeds: seeds with 1d soaking, followed by 1d incubation

Factor2: Seeding rate (2)

1. 30 kg ha^{-1}
2. 60 kg ha^{-1}

Factor 3: Establishment (2)

1. Wet Seeding
2. Water Seeding

Plot size: 5 m x 12.5 m= 62.5 m^2

Rep: 3

Design: Factorial RCBD

Measurements: The following measurements were taken: plant stand (number of plants m^{-2}), percent emergence (%), yield and yield attributes, and visual rating of lodging.

Results:

Yield: In wet-DSR, the yields of iron-coated and pre-germinated seeds were not significantly different (Fig. 31). However, in water seeding, iron-coated seeds resulted in an 11% higher yield compared to pre-germinated non-coated seeds. The results suggest that iron-coating technology can be used in both wet and water seeding establishment to reduce the risk of poor crop establishment by reducing seed drift if rain occurs immediately after sowing (Fig. 34).

Lodging: Lodging percentage is significantly higher in wet-DSR compared to water seeding (Fig. 32). Higher seeding rates are also more susceptible to lodging in wet seeded rice (Fig. 33)

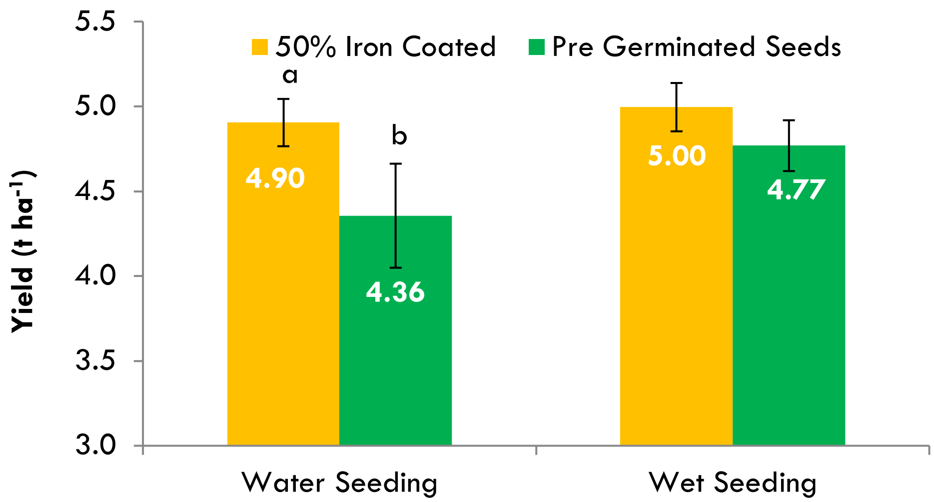


Figure 31: Yield of iron-coated and pre-germinated seeds in water-seeding and wet-seeding conditions with 60 kg ha^{-1} seed rate. Different letters indicate significant difference in treatments using Tukey's HSD test.

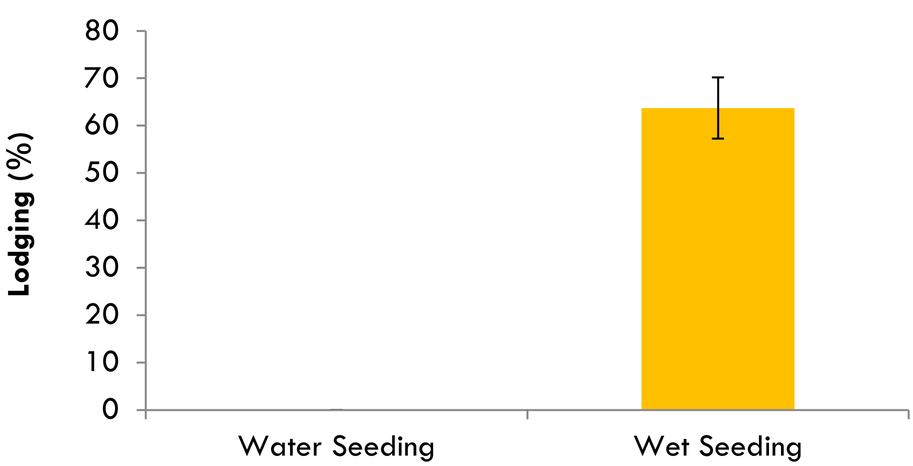


Figure 32: Lodging percentage under water-seeding and wet-seeding conditions with 60 kg ha^{-1} seed rate. Different letters indicate significant difference in treatments using Tukey's HSD test.

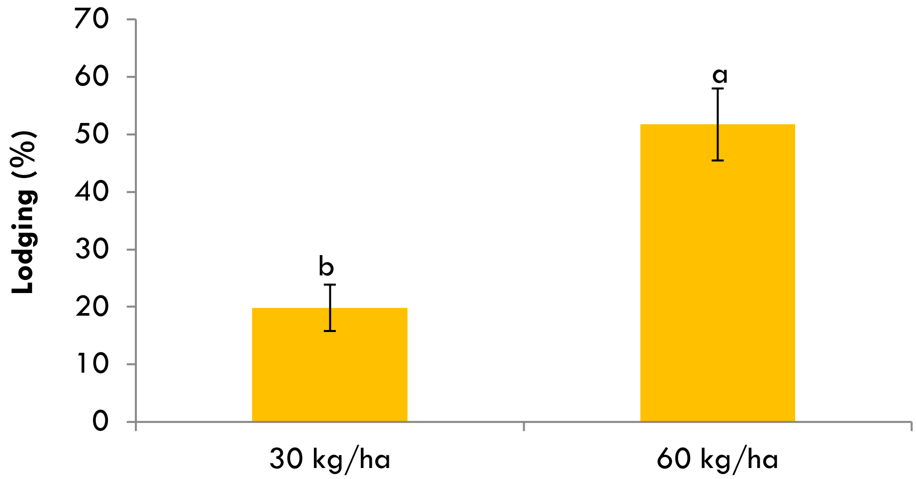


Figure 33: Lodging percentage under wet seeding with a 30 and 60 kg ha^{-1} seed rate. Different letters indicate significant difference in treatments using Tukey's HSD test.

Study 3: EVALUATING THE PERFORMANCE OF IRON-COATED SEED TECHNOLOGY ON CROP ESTABLISHMENT UNDER WATER SEEDING (CROP ESTABLISHMENT EXPERIMENT)

Objectives:

- Effect of seed-coating percentage on crop establishment and early crop growth
- Effect of duration of water seeding/flooding on crop establishment and early crop growth
- Effect of water seeding on weed infestation

Treatments:

Factor 1: Iron seed-coating ratio (4)

1. Pre-germinated seeds without iron coating (check): seeds with 1d soaking, followed by 1d incubation
2. 25% Fe-coated seeds
3. 50% Fe-coated seeds
4. 100% Fe-coated seeds

Factor 2: Flooding Duration (2)

1. No Flooding
2. 2 days continuous flooding of 5-cm depth after seeding
3. 4 days continuous flooding of 5-cm depth after seeding
4. 6 days continuous flooding of 5-cm depth after seeding

Plot size: 1x1 m = 1 m2

Rep: 3

Measurements: Plant stand (number of plants m^{-2}), percent emergence (%), crop biomass at termination (17 DAS), and weed infestation.

Results:

Percent emergence: The results showed that irrespective of iron-coating percentage, iron-coated seeds have a slightly higher rice emergence percentage compared to pre-germinated seeds, even under non-flooded conditions without early flooding (Fig. 34). This is probably because iron-coated seeds are less susceptible to bird damage and may improve seed-to-soil contact.

Crop emergence was negatively affected by increased duration of early flooding (Fig. 34), wherein iron-coated seeds were less affected than pre-germinated seeds without iron coating. Under no flooding, iron-coated seeds (50% and 100%) had an 11-15% higher emergence than non-coated pre-germinated seed. Crop emergence of non-coated, pre-germinated seeds was drastically reduced with 2d of early flooding compared to the iron-coated seeds (14% versus 64-76%). Iron-coated seeds with 2d of early flooding resulted in crop establishment similar to pre-germinated seeds without flooding. Beyond 2d of flooding, crop establishment was adversely affected in both coated and non-coated seeds; however, establishment was better in coated seeds than non-coated seeds at 4d (<1% versus 20-28%) and 6d (<1% versus 3-5%) of early flood duration.

Crop biomass at 17 DAS: Crop biomass of pre-germinated seed and iron-coated seed was not statistically different under no-flooding but was higher under flooded conditions (Fig. 35). Under flooded conditions, crop biomass was higher in coated than in non-coated seed because of higher establishment in the coated seed. In coated-seed, emergence was slightly delayed compared to the pre-germinated seeds; since the seeds were dry, emergence would technically be expected to occur a few days behind that of the pre-germinated seeds.

Weeds: The results showed that flooding can significantly reduce weed count (Fig. 36 A) and biomass (Fig. 36 B). The results also suggest that water-seeding facilitated by iron-coating technology could potentially be used as means of reducing weed problems, including weedy rice, in DSR.

These results suggest that water seeding with 2d of early flooding is feasible with iron-coated rice seed. Results also showed that just two days of early flooding was effective in suppressing weed establishment and growth. To improve the establishment of water-seeded crops with longer durations of early flooding, more research is needed, especially studies combining anaerobic-germination-tolerant varieties with iron-coated rice seed technology. DSRC will explore this further in upcoming seasons.

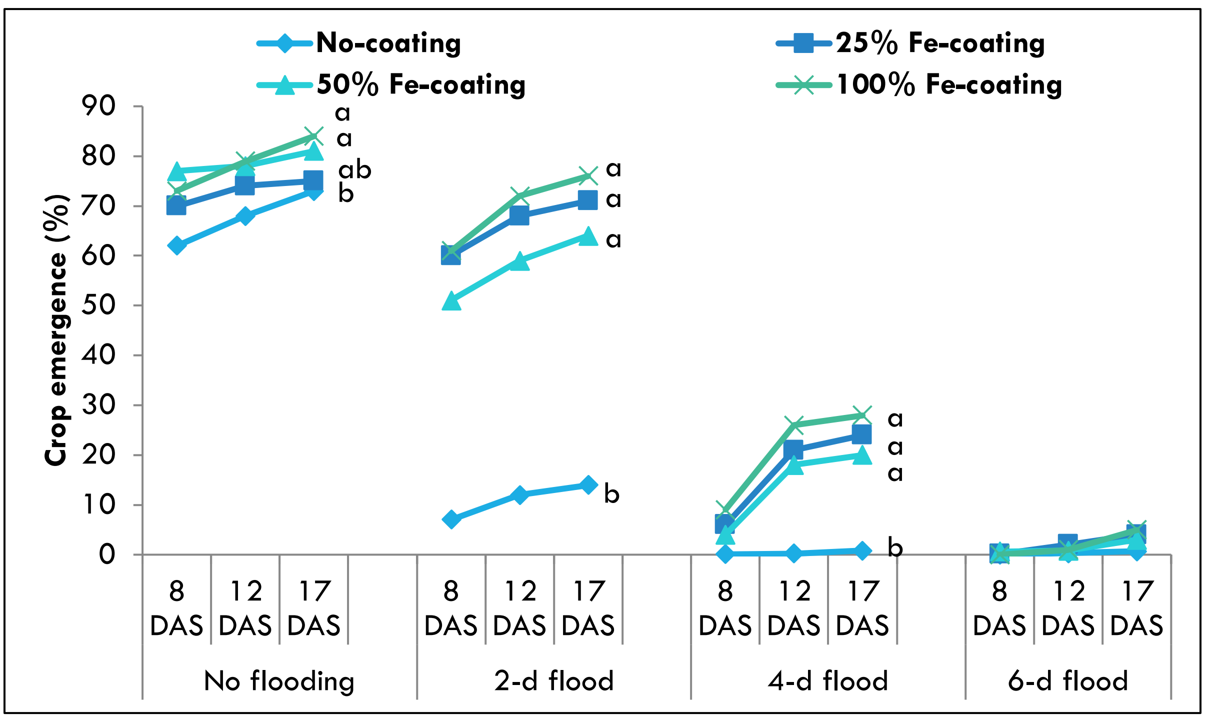


Figure 34: Crop emergence (%) at 8, 12, and 17 DAS of iron-coated seeds and pre-germinated non-coated seeds under no flooding and 2d, 4d and 6d duration of early flooding. Within each flooding duration, different letters indicate significant differences in treatments using Tukey's HSD test.

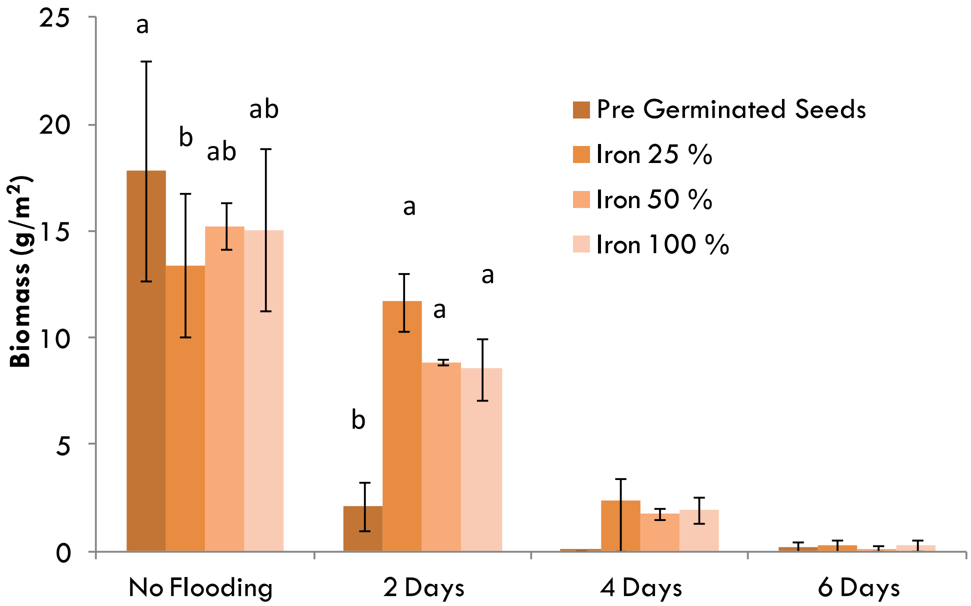


Figure 35: Crop Biomass at 17 DAS of pre-germinated and iron-coated seeds under no-flooding and different flooding conditions. Within each flooding duration, different letters indicate significant differences in treatments using Tukey's HSD test.

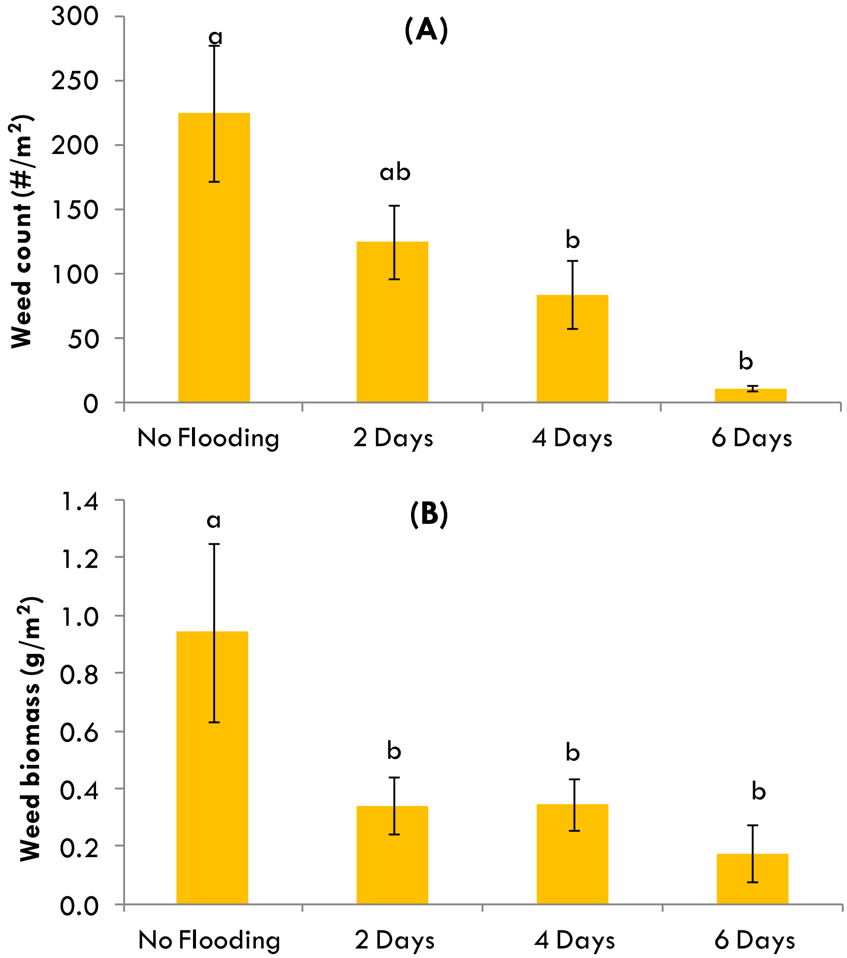


Figure 36. Weeds count (A) and biomass (B) of plots under different flooding regimes. Different letters indicate significant difference in treatments using Tukey's HSD test.

2.7. Medium-Term Multi-Criteria Performance Evaluation of DSR-Based Cropping Systems in the Philippines

Rationale: A number of studies have questioned the medium- to long-term sustainability of DSR-based systems because of yield decline with continuous use of DSR, including the emergence of new problems with weed build-up and soil sickness due to micronutrient deficiencies and nematodes. These findings call for targeted research to understand the processes contributing to yield decline. This study examines the multi-criteria performance of DSR-based cropping systems as compared to PTR and monitors the medium- to long-term sustainability by tracking changes in soil parameters, weed and pest dynamics, yield, economics, resource use, and life-cycle assessment.

Overall Objectives

1. To assess the short- to the long-term performance of different DSR-based cropping systems within key scenarios of agricultural change using a wide range of indicators (e.g., yield; efficiency of resource use efficiency; crop, soil, pest, and environmental (GHG) health; economics; and life cycle assessment.
2. To refine and parameterize models for assessing the performance of DSR-based systems under key futuristic scenarios and identifying technological options.

Treatments

T1 = Puddled transplanted rice (PTR) in wet season followed by puddled transplanted rice in dry season (PTR-PTR)
T2 = Wet-seeded rice in wet season followed by wet-seeded rice in dry season (WSR-WSR)
T3 = Dry-seeded rice in wet season followed by dry-seeded rice in dry season (DDSR-DDSR)
T4 = Dry-seeded rice in wet season followed by maize in dry season (DDSR-Mz)

Plot size: 14 m x 52 m = 728 m^2

Experimental design: Randomized complete block design with three replications

Commencement of the experiment: Late dry season 2019

Crop management practices: Details of crop management practices under different cropping systems during the 2019 late dry season and the 2019 wet season are given in Table 30.

Observation taken: Baseline soil data; crop growth parameters (crop establishment, time series data on plant height, crop biomass, leaf area index, and tiller density); weed data (weed count and biomass); resource use (irrigation water, labor in each operation, and energy input); environmental data (greenhouse gas emission); economics (production cost, gross income, and net-income); and yield and yield attributes.

Results

Yield and yield attributes: The 2019 dry season (DS) crop was the first cropping season in the cropping systems experiment. In the 2019 DS, the rice-equivalent maize yield was significantly higher than both PTR and dry-seeded rice but was on par with wet-seeded rice (Fig. 37 A). In the wet season, grain yields from the different cropping systems did not differ significantly (Figure 37 B).

Table 30: Crop management practices under different treatments during the 2019 DS and the 2019 WS

	Cropping systems			
	PTR-PTR	WSR-WDSR	DDSR-DDSR	DDSR-Mz
Laser leveling	Entire experimental areas was laser leveled prior to the start of the experiment			
Land preparation	Preparation was the same for PTR and WSR. The field was tilled with dry tillage as in DDSR, then the soil was puddled twice using a hydro tiller and leveled using wooden plank.		Preparation was the same for DDSR and Maize. Land was prepared dry using a 4-wheel tractor mounted with a rotovator. No wet-tillage (puddling).	
Sowing date	Dry season 2019 *Feb. 16: Seed soaking* *March 8: transplanting* Wet season 2019 *July 5: seed soaking* *July 25: transplanting*	 *February 16* *July 5*	 *February 16* *July 5*	 *February 16* *July 5*
Variety	Dry season 2019 *Mestiso 89* Wet-season 2019 *Mestiso 77*	 *Mestiso 89* *Mestiso 77*	 *Mestiso 89* *Mestiso 77*	 *P4097YHR*** *Mestiso 77*
Crop establishment	Transplanting (18-20-d old seedlings) in line, 20 x 20 cm spacing	In line (20-cm spacing) using drum seeder (Pre-germinated seeds)	In line (20-cm spacing) using 2-wheel tractor seed drill (Dry seeds)	In Line (20-cm spacing) using 2-wheel tractor seed drill
Fertilizer (N: P_2O_5: K_2O) kg ha^{-1}	Dry season 2019 *160:30:30* Wet season 2019 *120:40:20*	 *160:30:30* *120:40:20*	 *160:30:30* *120:40:20*	 *230:60:60* *120:40:20*
Weed management*	Dry season 2019 PRE fb 1 Hand weeding (HW) Wet season 2019 PRE fb POST fb1 HW	 same as PTR same as PTR	 PRE *fb* POST *fb* 1 HW PRE fb POST fb 1 HW	 Glyphosate as POST + 1 HW same as DDSR
Crop establishment	Transplanted in line (20 x 20 cm spacing). 18-20 d old seedlings.	Pre-germinated rice seeds sown in line (20 cm) using drum-seeder	Dry rice seeds were line sown using MP seeder with 20-cm row spacing	Dry maize seeds were line sown using MP seeder with 60-cm row spacing
Irrigation	Shallow flooding (2-3 cm) for first 2 wks after transplanting; succeeding irrigation was based on soil moisture tension (SMT) threshold at 10 kPa using tensiometers installed at 15 cm soil depth.	First 15d irrigated to keep soil surface near saturation for good establishment fb continuous shallow flooding for next 15-days; succeeding irrigation at 10 kPa SMT at 15-cm soil depth	For first 4 wks, irrigation as needed to keep soil surface moist to ensure good establishment; succeeding irrigation was based on SMT threshold at 10 kPa using tensiometers installed at 15 cm soil depth	Same as DDSR during wet season for rice. For maize: irrigation was applied based on SMT threshold at 30 kPa using tensiometers at 30-cm soil depth

** PRE: pretilachlor in WDR and PTR, whereas in DDSR it was oxadiazon or pretilachor; POST= bispyrbac; ** Maize hybrid*

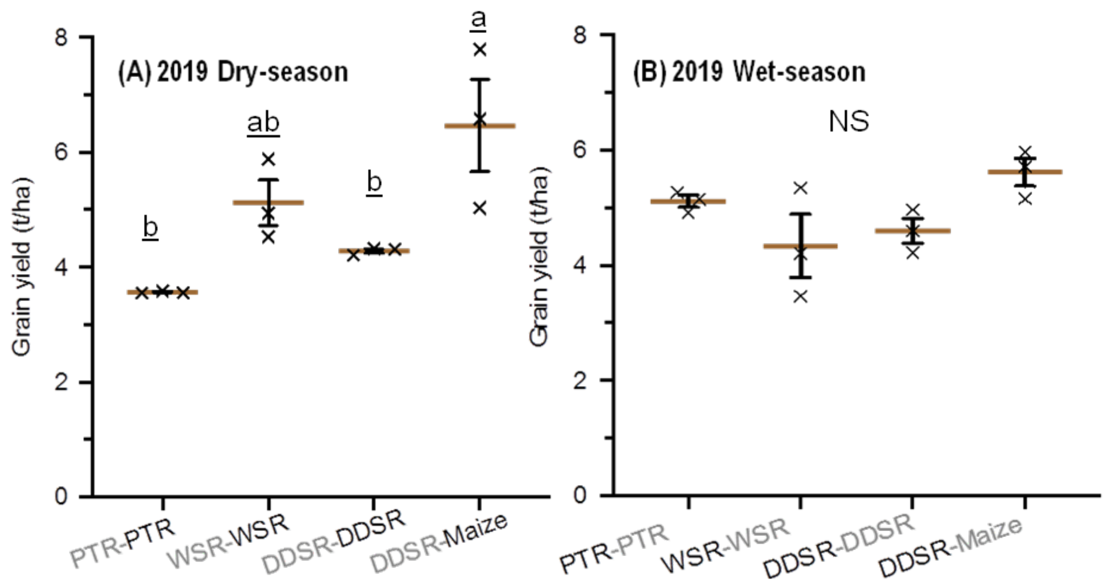


Figure 37. Grain yield of different rice-based cropping systems during (A) 2019 dry season, and (B) 2019 wet season. PTR = Puddled transplanted rice, WSR = Wet direct-seeded rice, DDSR = Dry direct-seeded rice. The brown line indicates the mean, the error bars represents standard error of mean (SEM), and "x" represent the individual replicates values.

Irrigation water and total water input: In the 2019 dry season, the average frequencies of irrigation for PTR, WSR, DDSR-R, and DDSR-Maize were 24, 27, 17, and 8, respectively. Irrigation and total water input was lowest in maize, which was lower than all of the rice treatments with different establishment methods (Fig. 39 A). Irrigation water input in maize was 42-53% lower than for rice with different establishment methods. Rice establishment method did not differ in terms of irrigation and total water input. This may be because in all rice treatments, irrigation was applied using the same criteria of 10kPa SMP at 15-cm soil depth.

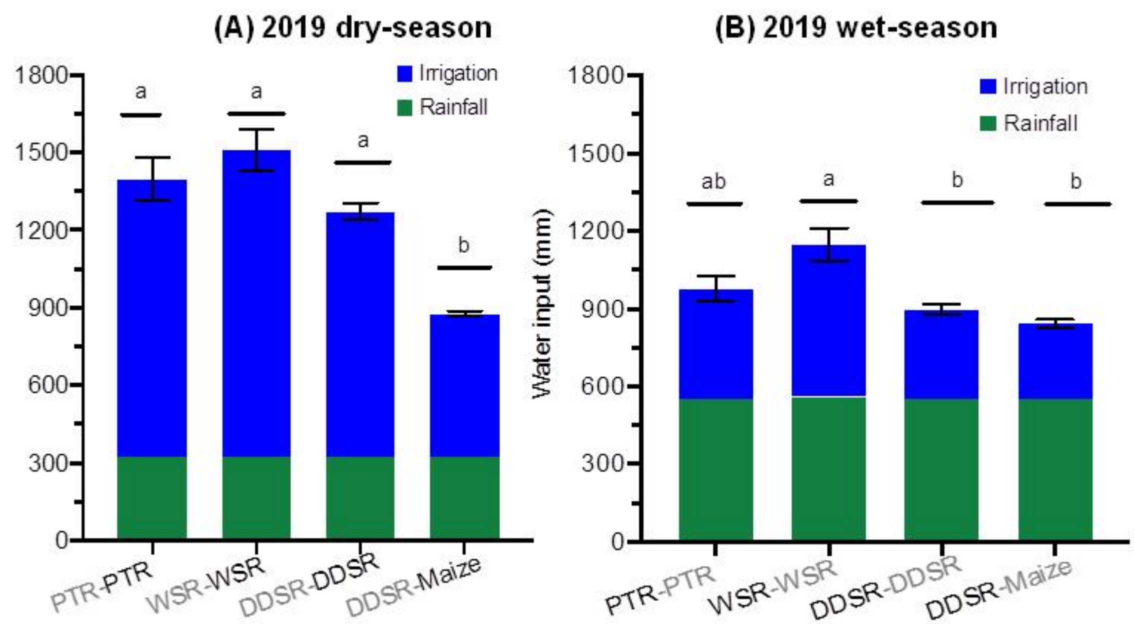


Figure 38. Irrigation water input and rainfall in the cropping systems experiment in (A) 2019 dry season and (B) 2019 wet season. PTR = Puddled transplanted rice, WSR = Wet-seeded rice, and DDSR = Dry-seeded rice. Rainfall: 332 mm in dry season and 551-560 in wet season. Different letters indicate significant difference in treatments using Tukey's HSD test.

In the dry season, the total rainfall (322 mm) was similar in all the treatments and was distributed in 24 events over the entire season (data not shown).

In the 2019 wet season, the highest irrigation water input was observed in WSR (587 mm) and the lowest was in DDSR plots (Fig. 38 B). Compared to wet-seeded rice, the water savings in dry-seeded rice ranged from 41-50%. Puddled transplanted rice had a medium level of irrigation water input and this did not differ between wet-seeded and dry-seeded rice. The rainfall received during the season slightly varies from 551 to 560 mm in different treatments. The 561 mm water input from rainfall was distributed into 58 events for the whole season. The average frequency of irrigation for PTR, WSR, DDSR-R, and DDSR-Maize were 11, 18, 9, and 9, respectively. The higher irrigation water in wet-seeded rice could be due to longer duration of main field. The likely reason for no difference in irrigation in PTR and dry-seeded rice could be because of same irrigation application criteria of 10 kPa. In PTR, alternate wetting and drying was followed which might have resulted in significant water saving compared to conventional flooded practice of water management in PTR.

2.8. Integrated Solutions for the Management of Weedy Rice

Rationale: Weedy rice has emerged as a major threat to rice production in DSR systems because it is highly competitive and difficult-to-control weed. In-season control options are limited, with the exception of hand weeding, because of its genetic, morphological, and phenological similarities to cultivated rice. As a result, there are no selective in-season herbicide options available for its management. Contaminated seed is thought to be one of the key reasons for its spread to new areas. Therefore, there is a need to develop integrated solutions for weedy rice management in DSR systems.

In Malaysia, scientists have recently explored the use of a pre-emergence herbicide (oxadiazon) in combination with flooding for 10 days prior to sowing and have observed 82-93% suppression of weedy rice (Masilamany et al. 2018). We also wanted to test this under Philippine conditions. In addition, many good cultural practices have been recommended for weedy rice management. However, there are a limited number studies quantifying the effect of these best cultural practices on yield and weedy rice control. Two experiments were conducted in the Philippines in collaboration with another of IRRI's projects known as WateRice (Water efficient and risk mitigation strategies for enhancing rice production in irrigated and rainfed environments).

Experiment 1: EVALUATING THE EFFECT OF PRE-PLANTING APPLICATION OF FLOODING + HERBICIDES ON WEEDY RICE SUPPRESSION AND RICE YIELD IN WET-DSR

Treatments:

T1 = Oxadiazon + flooding (5-cm) for 7 days prior to DSR sowing

T2 = Pretilachlor + flooding (5-cm) for 7 days prior to DSR sowing

T3= Farmer's practice of flooding/irrigation but no herbicide

Note: After crop establishment, establish flooding early than current farmer's practice (e.g., around the 8th day after seeding with shallow flooding and then increase it with increase in rice height.

Location: At farmers' fields in Iloilo (Region 6) in the Philippines in an irrigated system

Design: Randomized complete block with four replications

Method: Dry land preparation was performed about 15-days before DSR sowing. This was followed by wet tillage (puddling). About 10 days before sowing, pre-emergence herbicides (Oxadiazon and pretilachlor) were applied, plots were flooded to a depth of 5 cm the following day, and flooding was maintained for 7 days. Two days before sowing, plots were drained, final shallow tillage (not more than 5-cm deep) and land leveling were performed, and pre-germinated seeds of rice variety Rc-216 were sown. Good quality seeds were sown in line using a drum seeder. For T3, plots were managed as per farmers' practice. After sowing, all treatments were managed similarly as per farmers' practice, including weed management. Weed count and biomass, including weedy rice was monitored at 10-15 DAS, 30-35 DAS and at booting stage. Yield and yield attributes were collected at harvest.

Results:

Results showed that a combination of pre-emergence herbicides and flooding prior to sowing was effective in suppressing weedy rice and other weeds, and this improved rice grain yield in wet-DSR. Compared to farmers' practice, the yield increased by 34% (1.3 t ha^{-1}) in oxadiazon + flooding and by 16% (0.6 t ha^{-1}) in pretilachlor + flooding. Oxadiazon and flooding was more effective in suppression of weedy rice and other weeds. At 30 DAS, weedy rice density was reduced by 70% in oxadiazon + flooding and by 26% in pretilachlor + flooding. Similarly, the density of other weeds was 82 and 46% lower in plots treated with oxadiazon + flooding and pretilachlor + flooding, respectively, compared to no herbicide treatment. These results suggest that under irrigated systems where flooding for 7 days is feasible, oxadiazon in combination with flooding for 10 days prior to sowing could be an effective strategy in managing weedy rice under wet-DSR system. There was no phytotoxicity observed in rice establishment or growth.

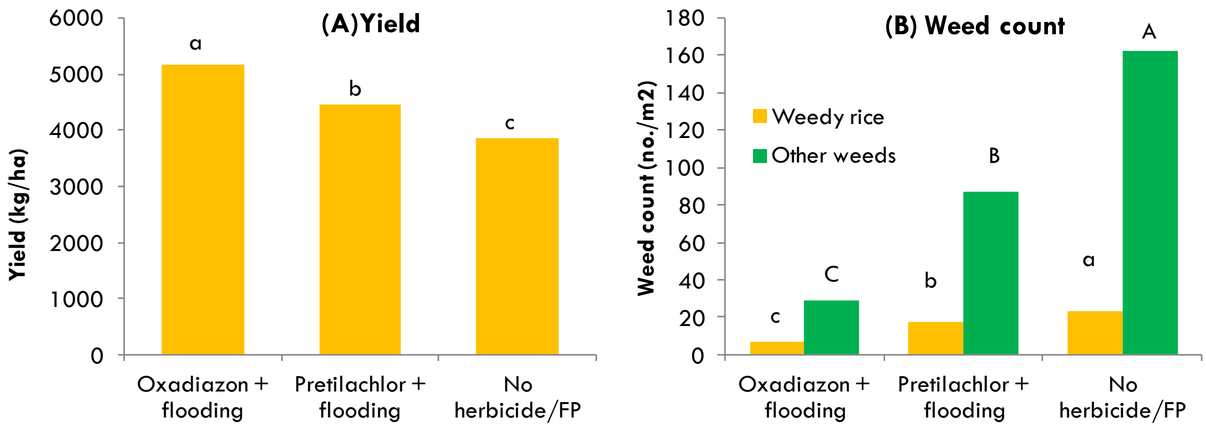


Figure 39. Grain yield (A) and weed count (B) under different weed management treatments. Different letters indicate significant difference in treatments using Tukey's HSD test.

Experiment 2: EVALUATING THE IWM PACKAGE FOR ITS IMPACT ON WEEDY RICE SUPPRESSION AND RICE YIELDS IN WET-DSR

Treatments:

Integrated weed management package (stale seedbed/good land preparation which includes first deep ploughing to bury weedy rice deeper in the soil fb shallow cultivation and good soil leveling prior to sowing; use of certified seeds free from weedy rice seeds with 60 kg ha^{-1} seeding rate (lower than farmer's practice); use of line sowing using drum seeder instead of broadcasting to facilitate early weeding/roughing; relatively early flood establishment (around 1 week after seeding instead of 10 DAS to suppress the growth of weedy rice, and one weeding; and herbicide program with PRE (pretilachlor with safener) fb POST (bispyribac + metamifop)

Farmers' practice (land preparation as per FP; broadcasting of their own saved seed using a higher seed rate (120 kg ha^{-1}), flood establishment as per FP (10-12 DAS). Herbicide program as per farmers' practice.

Location: The experiment was conducted in farmers' field in Iloilo (Region 6) in the Philippines in irrigated systems. 10 farmers were selected and each farmer acted as replication in which both treatments were tested.

Design: Randomized complete block with four replications

Method: Two treatments (IWM package and farmer practice) were establishment in 10 farmers' fields in Iloilo. Rice variety NSIC RC-216 was used. The plot size was 100 m^2. Each plot was managed as per the treatments above. Fertilizer and pest management were similar in both treatments.

Results: The IWM package reduced the weedy rice population by an estimated 49% and 60% at 30 days and at flowering, respectively, compared to farmers' practice (Table 31). Other weeds were also suppressed more in IWM than in FP treatment (data not shown). Lower competition from weedy rice in IWM plots resulted in 17% (0.6 t ha^{-1}) higher yield in IWM compared to FP.

Table 31. Yield and weedy rice density at 30 das and flowering under IWM and farmer's practice

	Yield	Weedy rice_30 days	Weedy rice_Flowering
	------t ha^{-1}-----	----------------------number m^2-----------------------	
T1 (IWM)	4.35 a	7.9 b	5.9 b
T2 (FP)	3.73 b	15.4 a	14.8 a

1 Within column, means followed by the same letter are not statistically different at 5% level of significance

3. CAMBODIA

In Cambodia, farmers rapidly shifted from PTR to broadcast DSR to cope with the rising scarcity of agricultural labor in the country (Martin et al. 2017). Prior to 2000, DSR was practiced in 10-30% of the total rice area, but by 2017, 90% of farmers were practicing broadcast DSR (Martin et al. 2017). This shift to broadcast DSR resulted in increases in the seed rate from 15-25 kg ha^{-1} to 150-330 kg ha^{-1} and additional weed-related problems (Flor et al. 2019; Martin et al., 2017; Chhun et al. 2019). The trade-off associated with the use of high seed rate was that farmers began using their own saved seeds, which are generally of poor quality, to reduce cost. Farmers' saved seeds also carry a high risk of weed seed contamination and seed-borne disease. In a recent study in Battambang province, Chhun et al. (2019) found that 1070 weed seeds were found in one kg of paddy seed. Moreover, agronomic practices such as broadcast seeding, higher seed rate, poor quality seeds contaminated with weed seeds and other pests, and sub-optimal fertilizer use under broadcast DSR have created conditions conducive to higher weed infestation and other incidences of pest, disease, and crop lodging resulting in pesticide lock-in, lower rice yields, and lower profitability from DSR methods than their potential suggests (Flor et al. 2019; Castila et al. 2020). For example, a survey conducted in 5 Cambodian provinces reported that Cambodian farmers rely on pesticides for pest control, using an average of 2-5 applications each of herbicide and insecticide and 1-6 applications of fungicide per season (Flor et al. 2019). All of these factors contribute to the need for optimization of agronomic management under DSR, including reducing the seed rate to enable farmers to use good quality seeds.

There is limited research documenting the value of quality seeds compared to farmers' saved seeds on farmers' yield and profitability. In addition, there is limited research examining enabling technologies that can facilitate use of lower seed rates and quality seeds. Mechanized DSR is one such enabling technology. Mechanized DSR with low seeding rates (40-80 kg ha^{-1}) will enable farmers to use good quality seeds free of weed seeds and diseases, thereby enhancing their productivity and profitability. CARDI and other development partners such as CAVAC (https://cavackh.org/), Syngenta Foundation (https://www.syngentafoundation.org/), and Agri-Smart (https://agri-smart.org/) and projects such as CamSID (https://aciarcambodiasidproject.wordpress.com/) and EPIC (https://ipmil.cired.vt.edu/our-work/projects/rice-ipm-for-cambodia/) seek to improve the productivity and profitability of Cambodian rice farmers by promoting the use of good quality seed and by achieving good and uniform establishment by increasing access to mechanized seeding with low seeding rates. Agri-Smart, has developed the Eli seeder to address the challenges of crop establishment in DSR.

Therefore, strategic research trials were conducted in collaboration with CARDI with the following objectives:

- Assessing the effect of seed source (good quality versus farmers' saved seed) and seed rate on agronomic traits and yields
- Optimizing the seed rate for DSR based on following factors: seed source (farmers' saved versus registered good quality seed), establishment method (line sowing versus broadcast, or a combination of both)

3.1. Assessing the Impact of Quality Seeds on Rice Yields in DSR

Experiment 1: ASSESSING THE EFFECT OF SEED SOURCE (GOOD QUALITY VERSUS FARMERS' SAVED SEEDS) AND ESTABLISHMENT METHOD (BROADCAST VERSUS LINE SOWING WITH SEED DRILL) ON CROP EMERGENCE, GROWTH AND YIELD

Collaborating scientist: Mr. Som Bunna and Dr.Ouk Makara, Cambodian Agricultural Research and Development Institute (CARDI), Phnom Penh.

Location of the Experiment: The experiment was conducted at the CARDI Research Farm in Phnom Penh, Cambodia during the early and main wet seasons in 2019.

Treatment:

Main plot: Seed source (3)

1. CARDI seed (Good quality certified seed)
2. Farmer's saved seed lot 1 (the farmer received registered seed from CARDI in 2018, one year ago, then grew this variety in dry season 2018 and saved the seed for sowing]
3. Farmer's saved seed lot 2 (the farmer, who owns the same variety, grew it in the previous season, dry season 2018, and saved the seed for sowing)

Note:

- For the early wet-season trial, rice variety CAR 15 was used. **For farmer's seed lot 1,** the seed lot of a farmer from Takeo province (Mr. Sor Bunthen), was used. He received registered seed from CARDI in 2018, grew it in the dry season of 2018, and saved the seed for sowing. **For farmer's saved seed lot 2,** a seed lot from Mr. Ream Veasna, from Prey Veng province, was used. He had his own CAR 15 varieties and also grew them int dry season of 2018 and saved the seed for sowing

- For the main wet-season trial, rice variety 'Phka Rumduol' was used. This is a premium aromatic photo-sensitive medium-maturity rice variety. For farmer's seed lot 1, a seed lot from a farmer from Battambang province, Mr. Soeung Sen, was used. He received the seed last year (2018), and it was categorized as a registered seed from CARDI in 2017. He grew it in the wet season of 2018, then he sold some of the seed and kept some of the seed for himself. **For farmer's seed lot 2,** a seed lot from a farmer in Takeo province, Mr. Pat Savoeung, was used. He had his own Phka Rumduol variety, grew in the 2018 wet season, and kept his own seed for the main wet season in 2019 (he is a seed producer).

Sub-plot: establishment method (2)

1. Broadcast DSR
2. Line sowing using CARDI seed drill

Other information about the experiment:

a) Early wet season 2019

Rice variety: CAR 15 Date of sowing: 4 April 2019

Experimental Design: Split plot Date of harvest: 20 July 2019

Seed rate: 80 kg ha^{-1} Fertilizer: as per CARDI recommendation

b) Main wet season 2019

Rice variety: Phka Rumduol **Date of sowing:** 23 July 2019

Experimental Design: Split plot **Date of harvest:** 22 Nov 2019

Seed rate: 80 kg ha^{-1} **Fertilizer:** As per CARDI recommendation

Experimental design: Split-plot with four replications

Observation collected: Assessment of seed quality (laboratory germination and purity), crop establishment at 15 and 45 DAS, plant height, rice biomass, and yield and yield attributes.

Results:

Seed quality assessment:

a) Seed lot of rice variety CAR 15 used in early wet season 2019: Although all of the seed lots had high scores for seed purity, the CARDI seed had the highest grain purity compared to the farmers' saved seed lots (96 % versus 91%) (Table 32). The amount of damaged, discolored, or diseased seed was higher in farmer's saved seed lot 2, which the farmer had for a longer time than both the CARDI seed (certified/breeder seed) and the farmer's saved seed from seed lot 1 (the newly saved seed)(15% versus 3%). The test weight of CARDI seed was higher than the farmers' saved seed lots. The germination % of CARDI seed was >91%, whereas the germination % of the newly saved seed (farmer' saved seed lot 1) was 73% and it was 65% in farmers' saved seed lot-2 – the one farmer had been saving for a longer time.

Table 32: Seed quality parameters of three seed lots of rice variety CAR 15 used in the early wet season 2019 experiment.

Parameter	CARDI seed	Farmer's saved seed lot 1	Farmer's saved seed lot 2
Grain purity (%)	96.2	91.4	91.0
Un-filled grain (%)	0.4	2.2	2.8
Grain skin disease/or damage (%)	3.4	3.4	14.6
Grain weight /1000-grain	28.2	26.6	27.1
Rice germination (%)	91.0	73.0	65.0

b) Seed lot of rice variety Phka Rumduol used in main wet season 2019: Similar to the results of rice variety CAR 15, overall, the seed quality of the farmer's saved seed lot of rice variety Phka Rumduol was also poorer than the CARDI seed lot (Table 33). Seed purity and germination % of farmer's saved seed lot 2 was low despite the fact that this farmer is a seed producer and sells seeds in his own and neighboring villages. The amount of weed seed was also high in farmer's saved seed lot 2 – 1.04% as compared to the standard acceptable limit of 0.5% for graded seeds. Contamination from seeds of other varieties was low in all the seed lots. The damage from insect-pests was also low in all the seed lots. The test weight (1000-grain weight) was highest in the CARDI seed lot (19.6 g), followed by farmers' seed lot 1 (27.6 g), and it was lowest in farmer's saved seed lot 2 (25.7). This suggests that CARDI seed may have higher early vigor compared to farmers' saved seed.

Overall, these results suggest the likelihood that the quality of seed will be poor if it is saved for a few years. The results also suggest that good quality seeds offer the potential to reduce seed rate and pest problems (insect pests or weeds) because the seeds have higher germination and are cleaner and less infested with insect-pests and diseases.

Table 33: Seed quality parameters of three seed lots of rice variety Phka Rumduol used in main wet season 2019 experiment.

Parameter	CARDI seed	Farmer's saved seed lot 1	Farmer's saved seed lot 2*
Grain purity (%)	98.3	95.1	88.0
Inert matter (%)	0.16	0.92	1.42
Weed seed (%)	0.05	0.12	1.04
Other varieties (%)	0.08	0.70	0.29
Insect damage (%)	0.10	0.60	0.12
Grain weight /1000g-grain	29.6	27.6	25.7
Rice germination (%)	98.5	93.8	85.3
Moisture content (%)	13.5	13.8	13.7

**Rice seed from the Osaray rice seed community*

Plant growth and yield

In early wet season 2019, rice yield was significantly affected by seed source but not by establishment method (Fig. 40). The grain yield was 23-26% higher when good quality CARDI seed was used as compared to farmer's saved seed. No difference in yield was observed between two seed lots of farmers' saved seed. Although the yield of DSR established with the CARDI seed drill was numerically higher than the yield established with manual broadcast, statistically, the yields of the two methods were not different.

In the main wet season, rice yields were affected by both seed source (p-value > 0.01) and establishment method (p-value >0.01). In addition, panicle length and weed biomass were also influenced by seed source (p-value >0.01). The interaction effect of seed source and establishment methods was non-significant for all parameters. The rice grain yield was 12 to 19% higher when good quality CARDI seed was used compared to farmers' saved seeds (Fig. 41). The grain yield was also 13% higher when established with the CARDI seed drill as compared to DSR established using the manual broadcast method. Weed biomass was 75% higher in plots seeded with farmer's saved seed lot 2 which had the highest weed seed contamination.

Based on the experiments conducted in both seasons, the results suggest that good quality seed provides a good opportunity to enhance grain yield in Cambodia where the majority of farmers use their own saved seeds. Line sowing using the CARDI seed drill also demonstrated a positive impact on grain yield compared to the manual broadcast method in one out of two seasons.

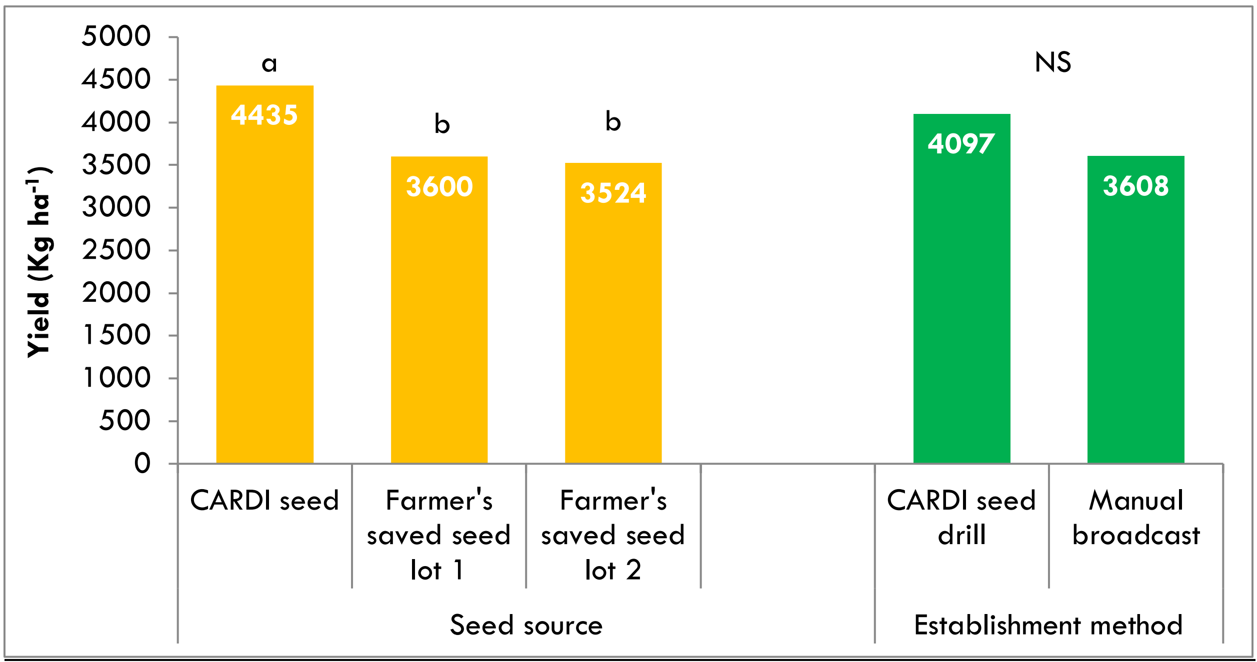


Figure 40: Rice grain yield of DSR with different seed source and establishment method at CARDI farm in Phnom Penh, Cambodia, during the early wet season 2019.

Note: Different lowercase letters indicate significant difference in seed source treatments. Establishment method effect was non-significant.

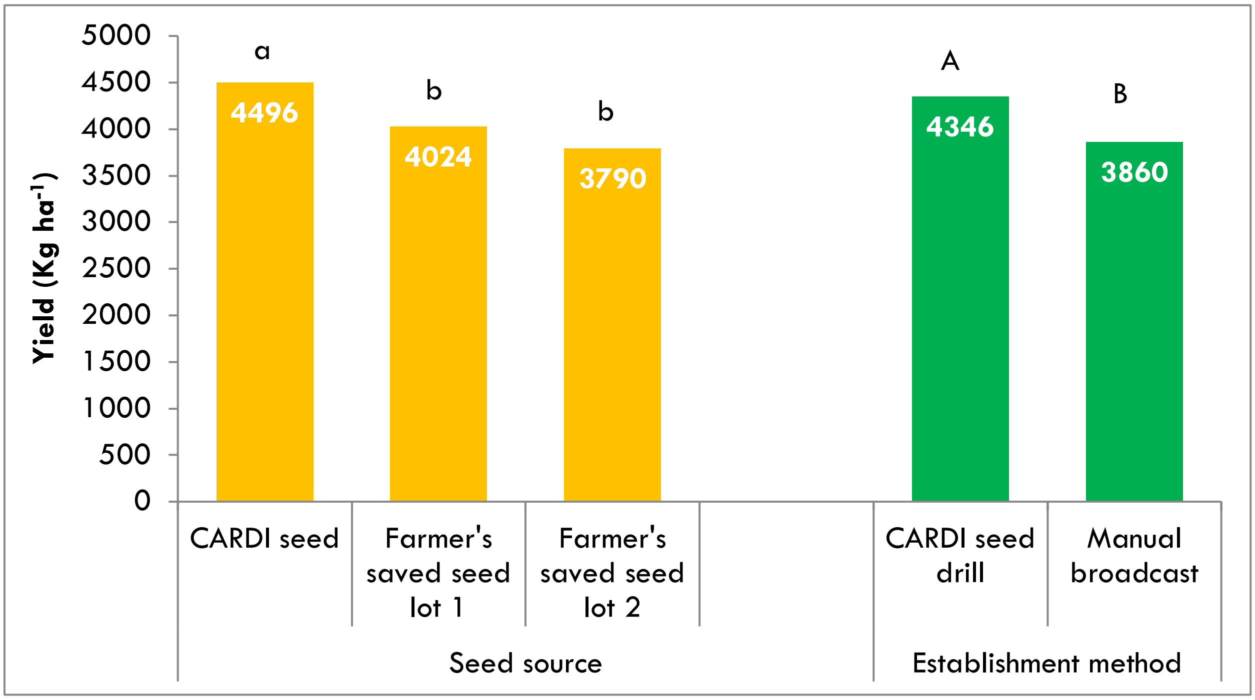


Figure 41. Rice grain yield of DSR with different seed source and establishment method at CARDI farm in Phnom Penh, Cambodia, during the main wet season 2019.

Note: *Different lowercase letters indicate significant difference in seed source treatments. Different uppercase letters indicate significant difference between establishment methods.*

3.2. Optimizing Seed Rate for Dry-DSR

Experiment 1: OPTIMIZING SEED RATE FOR DRILL-SOWN AND MANUAL BROADCAST DSR IN CAMBODIA

Treatments

Factor 1: *Establishment methods (2)*

1. Drill-sown
2. Manual broadcast

Factor 2: *Seed rate (4)*

1. 60 kg ha^{-1}
2. 80 kg ha^{-1}
3. 100 kg ha^{-1}
4. 120 kg ha^{-1}

Experimental design: *Factorial RCBD with four replications*

Other experimental information:

Rice variety: Phka Rumduol

Date of sowing: July 23, 2019

Experimental Design: Split plot

Date of harvest: Nov 22, 2019

Fertilizer: As per CARDI recommendations

Observation collected: crop establishment at 15 and 45 DAS, plant height, rice and weed biomass, and yield and yield attributes.

Results:

ANOVA results showed that rice grain yield was affected by both seed rate and establishment method, but their interaction effect was non-significant (Table 34). Plant density and weed biomass was also influenced by both seed rate and establishment method and their interaction effect was also significant, suggesting that the effect of seed rate varied with establishment method for these parameters. Plant height and panicle length was only influenced by seed rate and not by establishment method.

Rice yield in drill-sown DSR was 307 kg ha^{-1} (~9%) higher than with the manual broadcast method (Fig. 42). Among seed rates, rice yield was highest in plots with seed rates of 80 kg ha^{-1}, which did not differ from plots seeded at 100 kg ha^{-1}. However, the yield of plots seeded at a rate of 80 kg ha-1 was 11-15% higher than plots sown at seed rates of 60 kg ha^{-1} and 120 kg ha^{-1}. The yield of plots seeded at 60 kg ha^{-1} and 120 kg ha^{-1} did not differ. These results suggest that the 80 kg ha^{-1} seed rate is optimal to achieve maximum DSR yield under rainfed lowland rice systems.

Table 34. Summary of ANOVA model with effect of establishment method, seed rate and their interaction effect

Factor	Plant density	Plant height	Panicle length	Weed biomass	Grain yield
Establishment method (EM)	*	NS	NS	**	*
Seed rate (SR)	**	**	**	**	*
EM x SR	*	NS	NS	*	NS

*Note: ns - no significant difference, *- significant difference level p>0.05%, and **- significant difference level p>0.01%*

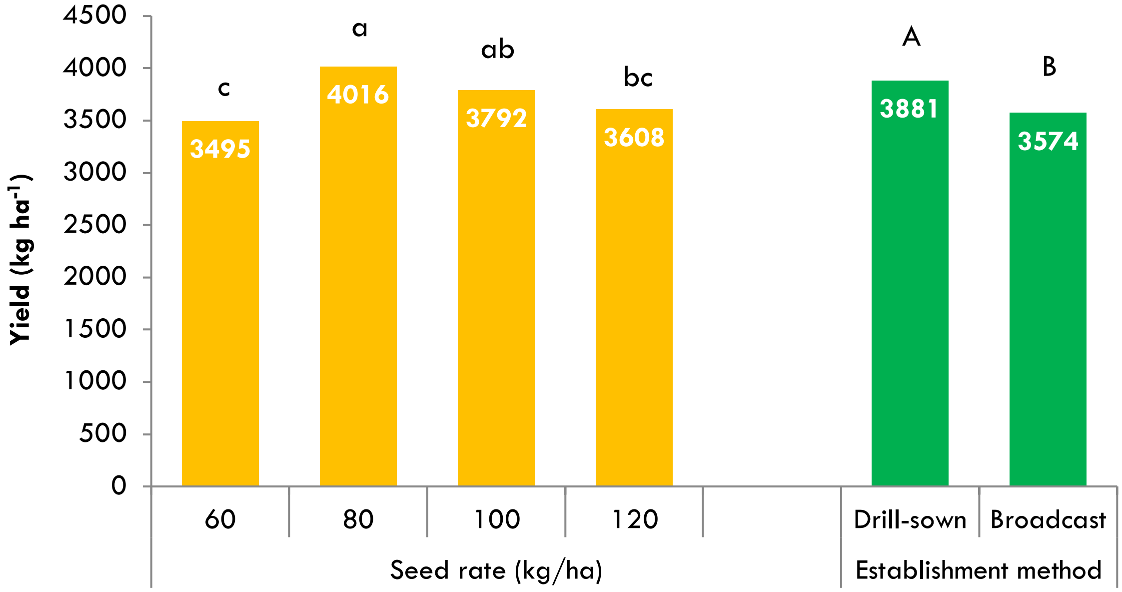


Figure 42. Rice grain yield as affected by seed rate and establishment methods. Note: Different lowercase letters indicate significant differences in seed rate. Different uppercase letters indicate significant difference among establishment methods.

Plant density was higher when DSR was established with the drill-sown method compared to broadcast DSR (233 versus 205 plants/m^2) (Table 35). This may be due to better placement of seeds and better seed-to-soil contact in drill-sown DSR. Plant density increased with increased seeding rate from 60 to 100 kg ha^{-1} but then declined when the seeding rate reached 120 kg ha^{-1}. Weed biomass was observed to be 18% higher under drill-sown DSR than under the broadcast method. The weed biomass decreased with increased seed rate from 60 kg ha^{-1} to 120 kg ha^{-1}. Compared to the 60 kg ha^{-1} seed rate, the weed biomass declined by 35%, 52%, and 64% in plots that had been seeded at seeding rates of 80, 100, and 120 kg ha^{-1}, respectively. These results suggest that a seed rate of 80 to 100 kg ha^{-1} is appropriate in Cambodia to achieve both the objectives of attaining higher yields and weed suppression. These results also demonstrate that there is enormous scope for reducing seed rate in Cambodia, as most of farmers in the country use seed rates in the range of 180 to 350 kg ha^{-1}.

Table 35. Plant density and weed biomass under different seed rates and crop establishment methods at CARDI in Phnom Penh, Cambodia, during the main wet season 2019.

Seed rate (SR)	Establishment method (EM)			Establishment method (EM)		
	Drill-sown	Manual Broadcast	Mean	Drill-sown	Manual Broadcast	Mean
	Plant density (# m^2)			Weed biomass (kg ha^{-1})		
60	181	166	173	93	85	89
80	245	216	230	68	49	58
100	310	238	274	50	37	43
120	197	199	198	32	33	32
Mean	233	205		60	51	
LSD $_{0.05}$ (EM)	15			4		
LSD $_{0.05}$ (SR)	21			6		
LSD $_{0.05}$ x SR)	NS			8		
CV	9			10		

3.3. DSRC network

A strong DSR research and development network has been established in Cambodia. Key research, development, and private sector partners involved include the following:

- Cambodian Agriculture and Development Institute (CARDI)
- Cambodia Agricultural Value Chain Program (CAVAC)
- Syngenta Foundation for Sustainable Agriculture
- Agri-Smart|Brooklyn Bridge to Cambodia (BB2C)
- Sydney University through Sustainable intensification and diversification in the lowland rice system in Northwest Cambodia (CamSID) Project
- Ecologically-based Participatory IPM Package for rice in Cambodia (EPIC) project

Through these organizations, mechanized and precise DSR with low seed rates has been widely demonstrated and disseminated.

The link to two recently introduced machines for DSR in Cambodia is given below and all stakeholders are now widely demonstrating and disseminating.

- Eli-Seeder https://www.youtube.com/watch?v=024Ein1ehXE

- Thai Kid Seeder (https://drive.google.com/file/d/1mC56KS9YYYxmJr1So0vewCeYr3DxdIPF/view)

Capacity Development

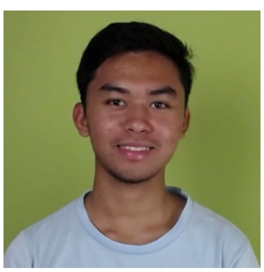
Capacity development is one of the objectives of the consortium. During 2019, the following participants were trained in DSR:

PhD, MS and BS degree research students:

Mr. Md. Iftekhar Mahmud Akhand from the University of the Philippines (UPLB), Los Baños is doing his PhD research at the DSR Field Laboratory at IRRI HQ in Los Baños,the Philippines. His research topic is *Medium-term multi-criteria performance of DSR-based cropping systems in the Philippines.*

Ms. Vasireddy Mani Chandana from Banara Hindu University in Varanasi is doing her PhD research at DSR Field Laboratory at the IRRI South Asia Regional Centre in Varanasi, India. Her research topic is *Evaluating drip irrigation systems for rice (DSR)-based cropping systems in eastern India for its diverse benefits.*

Ms. Zar Zar Soe from Myanmar completed her master's research at the DSR Field Laboratory at IRRI HQ at the end of 2019. She was enrolled at UPLB. Ms. Soe conducted research to identify rice cultivars that are more suitable for DSR conditions. Her research topic was *Yield and Weed competitiveness of rice cultivars under dry-seeded rice conditions.*



Mr. Leunell Chris Buela from the Philippines is doing his BS degree research at the DSR Field Laboratory at IRRI HQ. Mr. Buela is working on water advancement rate as affected by different soil preparation and planting methods.

Mr. Allan Tejada from the Philippines is doing his MS research at DSR Field Laboratory at IRRI HQ. His thesis research topic is *Analysis of the effect of geophysical controls on spatiotemporal variability of soil moisture.* He is enrolled as a master's student in water engineering at UPLB in the Philippines.

IRRI Technical team

Carlito Balingbing
Senior Associate Scientist; Mechanization and Post-harvest Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Ferdinand Corcuera
Research Technician; Soil, water, and Water Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Gopal Krishna Pandey
Research Technician; Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI-India office, Varanasi

Martin Gummert
Senior Scientist- Post Harvest Development; Lead of Mechanization and Post-harvest Cluster; Sustainable Impact Platform, IRRI, HQ, Los Banos, Philippines

Jerico Stefan Bigornia
Associate Scientist; Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Leodegario Dela Rosa
Research Technician; ; Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Lino Tatad
Research Technician – Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Olivyn Angeles
Senior Associate Scientist; Soil, water, and Water Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Pardeep Kumar Sagwal
Associate – Scientist; Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI-India office, Varanasi

Parveen Kumar, Research
Technician; Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI-India office, Varanasi

Sudhanshu Singh
Senior Scientist (Agronomy); Head, Broader Program for Research and Partnership (BPRP), ISARC Varanasi; Sustainable Impact Platform, IRRI-India office, Varanasi

Sudhir Yadav, Senior Scientist
Water Science; Lead of Soil, Climate, and Water Cluster; Sustainable Impact Platform, IRRI HQ, Los Banos, Philippines

Sylvia Villareal
Researcher; Adaptive Agronomy and Pest Ecology Cluster, Sustainable Impact platform, IRRI HQ, Los Banos, Philippines

Virender Kumar Senior scientist; Weed Science/Systems Agronomy; Lead of Adaptive Agronomy and Pest Ecology Cluster and DSRC Coordinator; Sustainable Impact Platform, IRRI, HQ, Los Banos, Philippines

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