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Research Article

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Screening of Rice Lines Under Aerobic and Alternate Wetting & Drying Rice Production Systems

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ABSTRACT

Over half of the world's population consumes rice, which is commonly grown in Asia by transplanting. The labour, water, and energy demand drive this production system, which has become less profitable as these resources become limited. Rice is a heavily irrigated crop in Asia, and saving water in rice cultivation systems has long been a priority of agricultural research. As worldwide water demand rises, aerobic or dry-seeded rice (DSR) irrigation with alternating wetting and drying (AWD) has become a viable water-saving method for rice cultivation. The DSR and AWD are gaining traction in several Asian nations by addressing water and labour constraints and improving system sustainability. The DSR and AWD strategies are beneficial in lowering water consumption, methane emissions, and production costs, resulting in increased productivity and profitability. However, DSR and AWD use in Pakistan is not prevalent due to policy implications, including educating farmers on the benefits of DSR and AWD and promoting the broader use of water-saving techniques. Therefore, the study aimed to screen the rice lines against DSR and AWD techniques to promote these technologies. The results showed that all rice lines performed well under DSR and AWD. Using these techniques, water savings ranged from 25–32%, along with a 14% increase in production. The study recommends that the AWD 15 be used in farmer's fields to increase productivity while maintaining quality. In conclusion, the research suggested that farmers use both strategies to save on inputs while increasing profits.

Keywords: Aerobic rice, AWD, Transplanted rice, Basmati rice, Water management, DSR

INTRODUCTION

Rice is Pakistan's second-most significant food crop, accounting for 10% of the country's cultivated acreage, 27% of total grain production, 3.5% of agricultural value added, and 0.7% of GDP (Govt. of Pakistan, 2021). Approximately 40% of the rice output (2.60 metric tons) is used locally, with the other 60% (3.90 metric tons) exported (USDA 2021).

The most widely adopted method of rice sowing is manually transplanting 30-35-day-old rice seedlings (growing elsewhere) into waterlogged and puddled areas (Ishfaq *et al.*, 2020). Poor crop management techniques also lead to low crop production. The existing rice production system is inefficient, resource-intensive, and unsustainable. Decades of constant puddling have weakened the physical properties of the soil because of the dispersion of clay and the structural breakdown of soil aggregates and capillary pores (Sun *et al.*, 2015). Puddling restricts root penetration and the growth of crops that come after rice by forming a compacted layer that stops water from percolating and causes temporary waterlogging (Sun *et al.*, 2015). The leading causes of low yields in conventional approaches include low plant population and low nitrogen-use efficiency in paddy rice (≤ 40%) (Mann *et al.*, 2011). Therefore, relying on labour- and water-intensive rice production techniques will not be economical. Improved rice production systems are more practical for producing high-quality food on marginal or degraded land with limited resources (labour, water, and inputs) (Sun *et al.*, 2015). The aerobic system (DSR) and the

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alternating wetness and drying (AWD) system are two strategies that are becoming more and more relevant as alternatives to address these issues (Lampayan *et al*., 2015; Mahajan *et al*., 2017).

The DSR system is a revolutionary method of farming rice that uses less water than irrigated lowland rice. It comprises sowing rice directly in aerobic soil to produce maximum yields. The DSR technique has various benefits over traditional rice transplanting. DSR rice may save 30-35% of water while eliminating procedures such as rearing, care, nursery uprooting and shipping, and hand transplanting. Physical qualities stay stable in aerobic soil while nutrient availability improves (Nawaz *et al*., 2019). In aerobic or direct-seeded rice, optimal plant density may be obtained; however, in transplanted rice, a low plant population remains a major limitation to poor paddy production. Furthermore, the rice crop does not lodge under aerobic conditions, and field preparation following aerobic rice harvest is simplified, resulting in increased wheat crop establishment and yield (Nawaz *et al*., 2019). Aerobic rice growing is environmentally friendly since it produces fewer greenhouse gases, such as methane. The main characteristic of aerobic rice farming methods is the direct seeding of rice, which may be done on a well-prepared field, and seed may be drilled into rows 7-9 inches wide. This approach allows for quick watering. If a farmer does not own a seed drill, he or she can disseminate rice seed in a well-prepared field at optimal moisture levels, followed by planking (Mann, 2007; Nawaz *et al.*, 2019).

The AWD method is used with transplanted rice. Rather than flooding the rice field continuously, the AWD technique may be used to successfully generate puddled and transplanted rice harvests. After 30-40 days, transplanted rice can be watered every 6-9 days to sustain the crop at the optimal moisture level (Lampayan *et al*., 2015). In this strategy, the Basmati rice crop saved more than 20% of its water while increasing its production significantly compared to the usual flooded crop (Mote *et al*., 2021). This demonstrates that rice crops with AWD may be farmed effectively without significant yield loss. This approach may be used in standard basmati growing belts.

Keeping in view the above discussion, the rice lines received from the International Rice Research Institute (IRRI), Philippine and indigenous rice varieties were utilized to test against DSR and AWD. The study aimed to screen out the rice lines that performed best in DSR and AWD for the promotion of the new production technology. Suitable crop rotation and weed management techniques for DSR and AWD were also suggested in this study.

MATERIALS AND METHODS

Study Site

The study was carried out at the Rice Research Institute Kala Shah Kaku, Punjab districts (Gujranwala, Hafizabad, Narowal, Sheikhupura, Sialkot, Chiniot), and Sindh district (Dokri, Larkana, and Thatta).

Experimental Techniques

The two water-saving techniques, direct seeded rice (DSR) and alternate wetting and drying (AWD), were used in this experiment. The study was conducted in 2006-2009 and 2016-2021 for IRRI rice line screening and basmati and non-basmati varieties, respectively.

Direct Seeded Rice (DSR)

The DSR was conducted on a dry seedbed that had been thoroughly prepared with two passes of a tine cultivator followed by one pass of a rotary tiller (rotavator) with the aid of a rice drill attached to a tractor. After seeding, irrigation was applied immediately and a day later, pendimethalin was sprayed as a pre-emergence weedicide in muddy soil conditions. After applying a pre-emergence weedicide, the irrigation was repeated approximately 4 to 5 days later. Thereafter, it was spaced out by 3-5 days until the tillering period, and then 5-7 days till crop maturity.

Alternate Wetting and Drying (AWD)

30 days old rice seedlings were transplanted under properly levelled puddled field conditions in standing water with a plant spacing of 22.5×22.5 cm^2 with one seedling per hill. For the first 15 days after transplanting, a 5.0 cm water depth was maintained to promote better seedling establishment without any water stress and to enhance the efficacy of herbicides for better weed control. Thereafter, drying-and-wetting alternation treatments were imposed and the field was left to dry out until the water level was at 15 cm below the soil surface. Then, the field was flooded again to a water depth of approximately 5 cm before draining again. The AWD protocol was followed throughout the growing period of rice until 2 weeks before the expected harvest time, except for the flowering stage, which was the most critical stage of rice and was the only time when field was kept ponded from one week before flowering initiation to one week after flowering completion with 5.0 cm depth of water to avoid spikelet’s sterility and yield loss (IRRI 2009, Ali *et al*., 2022). After flowering, the previous practice was kept continued. A 2-meter PVC pipe was used to monitor the field's groundwater table while a "Water Meter" assessed the amount of water applied to the rice crop. Rainfall-related water contribution was also taken into account. To conduct experiments, Basmati varieties were transplanted into in subplots with two irrigation regimes (AWD and flooded)—main plots.

Comparing four different irrigation regimes: continuous flooding irrigation (CFI) AWD15, AWD20, and AWD25, in which plots of each AWD treatment were re-flooded to a depth of roughly 5 cm when the water level dropped to a specific level (15, 20, and 25 cm) below the field surface.

Crop Rotation

Three rice-based cropping patterns—rice wheat, rice chickpea, and rice mustard—were the focus of the experiment, which was conducted at RRI, Dokri. Rice was sown with a 20 cm space between lines at a rate of 50 kg/ha. A non-replicated experiment was conducted and the yield of both rotational crops in each treatment was assessed. The standard production technology was followed throughout the cropping season of both crops. There was no other factor considered as a variable other than the crop itself.

Weeds Control

A direct planting strategy with seven treatments e.g. Nominee, Nominee + hand weeding, Sunstar, Sunstar + hand weeding, One-Hand weeding, Two-Hand weeding and the Control, has been used in an experiment at RRI's farm in Kala Shah Kaku. Super Basmati, a basmati rice cultivar, was directly planted at a rate of 30 kg/ha. Sunstar as a pre-emergence herbicide @ 200 gms/ha (Sodium 2,6 bis-benzoate), applied after seeding + one hand weeding at the fifth week; and the Nominee as a post-emergence herbicide @ 250 ml/ha (Ethoxy sulfuron), applied at 2-3 weeks; e) one hand weeding at the third week of seeding; two hand weeding at the third and fifth week; and no weeding (control). For the trial, a spilled-plot design was replicated three times. It was decided to apply the recommended quantity of fertilizer (120-60-0 kg NPK/ha), treating all P as basal and applying N in three splits (25, 50, and 70 days after planting).

Data Collection

This experiment measured yield-related attributes, plant height, crop maturity days, total water input, water productivity, water savings, and the cost of water savings. The population of different weed species before and after the application of herbicides and hand weeding was also considered. For the crop rotation experiment, gross income, net income, and the variable costs of different inputs were also taken into account. Statistix 8.1 software was used for statistical analysis of the data and onward mean comparison of different variables.

RESULTS AND DISCUSSION

Testing and Evaluation of Basmati and non-Basmati groups

At the first location, all cultivars did well using both strategies. KSK-133, a coarse rice variety, generated the greatest rice grain yield of 5.02 t/ha under AWD, whereas Line No. 99421 produced the best yield of 4.82 t/ha by direct seeding (Table 1). The Department has recognized the KSK-133 variety for general cultivation in Punjab. Under average field conditions, this variety may yield 7.20 t/ha of rice. Similarly, under AWD and DSR water stress conditions, the two Basmati varieties, Super Basmati and Basmati 2000 had the highest yields (Table 1).

Table 1: Average rice yield (t ha^{-1}) of local rice varieties/lines

Variety/Line	Paddy Yield (t/ha)		
	Transplanted & flooded	AWD	Dry Direct Seeding
Non-Basmati Group			
IR-6	4.53	4.66	4.86
IR-9	5.04	5.38	5.71
KS-282	4.87	4.94	4.92
KSK-133	4.98	5.02	4.99
99421	4.96	5.12	4.98
IR-54742-31-9-26-15-2	4.44	4.61	4.55
PK-3300-12-2	4.24	4.34	4.31
PK-3699-43	4.32	4.58	4.47
PK-3355-5-1-4	4.60	4.80	4.70
99723	3.56	3.64	3.67
Basmati Group			
Bas-370	4.27	4.44	4.35
Bas-198	4.00	4.32	4.10
Bas Pak	3.57	3.73	3.69
Bas-385	4.42	4.60	4.57
Super Basmati	4.30	4.50	4.59
Bas-2000	4.77	4.84	4.80
60001	4.58	4.67	4.61
49731	3.75	3.84	3.83
40265	3.67	3.87	3.72
52773-2	4.45	4.55	4.51
33608	4.31	4.39	4.44

97502	4.41	4.56	4.49
Shaheen Basmati	3.32	3.57	3.51
98316	3.67	3.74	3.72
99417	2.75	2.82	2.77
98506	3.57	3.63	3.59
PK 5261-1-2-1	4.28	4.39	4.36
PB-95	3.64	3.85	3.74
SSRI-8	3.15	3.46	3.52
SSRI-13	3.49	4.13	3.50

In 2017, the districts of Gujranwala, Hafizabad, Narowal, Sheikhupura, and Sialkot had 20 field demonstrations of DSR using modified seed drills. Compared to manual TPR, the Super Basmati rice variety was immediately planted. According to Table 2's overall findings, paddy output increased by 15.1% under DSR compared to TPR. Furthermore, more than 2500 farmers in Pakistan's Punjab Province farmed rice using DSR in 2017 on an area of around 10,000 hectares and discovered that it was more economical than manual TPR. Therefore, to reap the most rewards, farmers might choose to use this technology. In both PTR and DSR, an irrigation threshold of -20 kPa was the best for optimizing grain output and conserving water (Table 2). The second research that covered the years 2018–2021 found that irrigation water savings were achieved in both dry-seeded rice (DSR) and puddled transplanted rice (PTR) under average and somewhat well-distributed rainfall, as well as alternating wetting and drying (Table 3). In un-puddled transplanted rice (UTR), the irrigation water productivity of DSR at AWD15 (-20 kPa) was comparable to that of AWD 15 (-20 kPa), but the grain yield in UTR was 6% less than that of CFI (Table 3). In comparison to UTR at the same irrigation levels, rice planted with dry seeding was more susceptible to growing water constraints, which led to a lower grain yield. In the second site, rice cultivars such as "DR-92" and "Shahkar" yielded the highest yields under conditions of water stress (Table 4). In the province of Sindh, farmers have lately been allowed to cultivate the Shahkar variety on a broad basis. The study has produced extremely useful information: cultivars with broad adaptability, such as Super Basmati, Shahkar, KS-133, and Basmati 2000, may thrive in environments with less water. Farmers in the target region also got seeds of some of the newest high-yielding kinds in the shortest time feasible.

Table 2. Average of 20 locations for the two planting techniques

Planting method	Plant height (cm)	Productive tillers m^{-2}	Number of grains per panicle	1000-grain weight (g)	Paddy yield (t ha^{-1})	Difference in grain yield (%)
DSR	130.2	411	103	19.1	4.20	15.1
Transplanted Puddled Rice	134.4	362	111	20.3	3.65	0

Table 3. Comparison between irrigation treatments for their effect on water-saving efficiency and grain yield

	Irrigation treatments	Water input (mm)	Difference in water input (%)	Grain yield (t ha^{-1})	Difference in grain yield (%)
UTR	CF	871.5	0	3.29	0
	AWD15	836.1	-4.1	3.27	-0.6472
	AWD20	745.6	-14.4	2.97	-10.356
	AWD25	692.6	-20.5	2.5	-25.566
DSR	CF	869.6	0	3.09	0
	AWD15	790.7	-9.1	3.16	2.2654
	AWD20	714	-17.9	2.67	-13.592
	AWD25	654.4	-24.7	2.45	-20.712

Note: A negative sign indicates a decrease in value

Table 4. Average rice yield (t/ha) of local rice varieties/lines, planted with three methods

Variety/Line (Course)	Yield (t/ha)		
	Transplanted & flooded	AWD	Direct Seeding
IR 8	7.35	7.56	7.53
IR 6	6.23	6.31	6.26
DR 82	5.71	5.88	5.75
DR 83	5.53	5.57	5.56
DR 92	6.99	7.09	7.01
S. Hayat	5.60	5.64	5.61
Lateefy	3.55	3.68	3.63
DR 64	6.61	6.75	6.78
DR 65	4.16	4.32	4.42
DR 66	4.26	4.52	4.43
DR 58	7.48	7.61	7.57
DR 67	4.52	4.56	4.57
Shahkar	8.36	8.54	8.42

Testing and Evaluation of IRRI Material for Aerobic & AWD:

A total of 251 lines under the categories of aerobic, rainfed, and irrigated-lowland were received by the Rice Research Institutes at Kala Shah Kaku & Dokri from the IRRI, Philippines, between 2006 and 2009 for testing and evaluation in the local environment during the duration of the Asian Development Bank project (ReTA 6267). Seven lines were chosen from 36 entries by our KSK experts to fall within the aerobic lowland category (Table 5). The findings showed that grain yield was greater in the aerobic entries designated as IR 79597-56-1-2-1, IR 80416-B-152-4, IR 80416-B-32-3, and IR 70210-39-CPA-7-1 than in the local checks. The IRRI entry generated a yield in the range of 5.4-5.9 t/ha, whereas the local check (KSK 133) yielded a maximum yield of 5.6 t/ha. From these lines, enough seed was generated to be utilized in further breeding. Similarly, among 41 (rainfed lowland) IRRI entries at KSK, 7 lines were also chosen (Table 6). Grain yields of 6.1 t/ha were generated by the entry with the identification IR 82082-B-B-96-1, which was followed by IR 82311-B-B-1-2 and IR 82293-B-B-31-1, with a grain yield of 6.0 t/ha. These entries mostly have desirable qualities. In contrast, the grain yield from the local inspections was between 5.5 and 6.1 t/ha. These lines feature a moderate plant height, a strong tillering capability, and a maturity time of up to 110 days. Likewise, Thatta (Lower Sindh) planted nine entries. Table 7 displays rice grain yield, Results showed that the IRRI lines required 110–116 days to reach maturity and reached a height of 97–125 cm on the plants (Table 7). In contrast to the local check's 4.41 t/ha, the grain yield ranged from 4.02 to 4.68 t/ha (DR-92). The IRRI lines show very promising grain yield statistics, and they may eventually replace the long-standing local variety. The goal of large-scale seed multiplication is now being pursued. They were evaluated for a second crop season to assess these lines' effectiveness in the local environment even more. The exchange of this important IRRI material greatly enhanced the local breeding program for drought tolerance.

Table 5. Selected lines from Advanced Yield Trial-I (Aerobic)

Variety/Line	Height (cm)	No. of Productive Tillers/Plant	Panicle Length	Paddy Yield (t ha^{-1})
IR 72	79.8	14.6	26.3	5.5
IR 77080-B-34-1-1	108.9	11.8	25.6	5.7
IR 79597-56-1-2-1	104.9	12.2	26.2	5.9
IR 80416-B-152-4	111.5	12.9	26.2	5.8
IR 80416-B-32-3	107.0	14.7	26.8	5.9
IR 70210-39-CPA-7-1	113.7	14.7	24.1	5.8
IR 82870-11	82.1	14.1	24.3	5.4

Table 6. Selected lines from Advanced Yield Trial –II (Rainfed Lowland)

Variety/Line	Height (cm)	No. of Productive Tillers/Plant	Panicle Length	Paddy Yield (t/ha)
IR 82287-B-B-77-2	117.9	15.9	25.4	5.6
IR 82082-B-B-96-1	132.1	16.1	25.9	6.1
IR82298-B-B-86-1	120.3	14.4	24.1	4.4

IR 81388-B-B-66-3	119.5	14.2	22.6	5.1
IR 81026-B-126-4-2	106.8	11.4	26.4	5.6
IR 82311-B-B-1-2	115.1	11.7	24.8	6.0
IR 82293-B-B-31-1	136.4	11.8	27.9	6.0

Table 7. AYT-Aerobic 110-120 days' duration planted

Entries	Days to Maturity	Plant height (cm)	Yield (t ha^{-1})
IR 81413-B-B-75-2	111	107	4.53
IR 81449-B-B-109-3	112	112	4.58
IR 81449-B-B-116-4	113	92	4.48
IR 81449-B-B-128-1	113	102	4.54
IR 81449-B-B-51-4	112	101	4.64
IR 82319-B-B-103-2	116	115	4.73
IR 81454-B-B-57-1	107	105	4.51
IR 82098-B-B-18-2	117	124	4.27
IR 82320-B-B-29-2	108	103	4.45

Participatory Varietal Selection under Aerobic and AWD:

At Haji Sons Farm, which is close to Chiniot, Punjab, the most promising rice types were planted using the AWD technique. The findings showed that IR 82082-B-B-96-1 generated the highest paddy yield at 8.4 t/ha, while KSK-282 provided the second-highest yield at 8.2 t/ha (Table 8). The range of plant heights was 110–134 cm, while the range of productive tillers per square meter was 190–384. Similar to this, two local checks and eight IRRI lines/varieties were drilled in Sindh Province using 50 kg/ha of seed. A total of 120-60-37 kg NPK/ha of fertilizer, including all phosphorus and potash, was sprayed at basal. According to Table 9's data, grain yield varied between 1.72 and 5.34 t/ha. Both medium maturity period and medium size were among the entries examined in the mother trial. It took considerably longer for the entry designations IR67017-8-2-1-141 and IR28068-99-1-3-3 to develop than it did for the other entries. With a yield of 5.34 t/ha, the entry number IR79906-B-192-2-4 outperformed the check varieties DR 92 and Shahkar. Similarly, elongated panicles were produced by the same entry. During the rice crop's flowering stage, local farmers visited the PVS fields and expressed a keen interest in the rice varieties' performance. The objective had been to assess the possible rice varieties at the farm level and convince neighboring farmers to use them for the next season. KS-133 was on display in the Chiniot region of Sindh province, while Shahkar and DR-92 were in the Larkana district. A significant factor in quickly distributing novel technologies or varieties is farmers' participatory research.

Table 8. Participatory varietal selection at Chiniot

Variety	Height (cm)	No. of Productive Tillers/m^2	Panicle Length (cm)	Yield (t ha^{-1})
IR 82082-B-B-96-1	128.2	254	25.0	8.4
IR 82311-B-B-1-2	126.0	227	28.0	7.4
IR 82293-B-B-31-1	101.4	248	25.0	7.5
IR 79597-56-1-2-1	119.2	210	24.8	6.2
IR 80416-B-152-4	126	190	25	7.2
IR 80416-B-32-3	134.2	193	29	7.6
IR 70210-39-CPA-7-1	117.6	384	30	8.2
Mean	121.7	243.7	26.7	7.5

Table 9. Participatory varietal selection at Larkana

Entries	Maturity	Height (cm)	Panicle length (cm)	Spikelets/panicle	Yield (t ha^{-1})
IR67017-8-2-1-141	114	83.67	22.67	107.33	1.72
IR83885-1-1-4	108	93.67	19.33	87.00	2.86
IR28068-99-1-3-3	115	103.67	22.00	94.00	3.47
IR80312-6-B-3-2-B	108	108.00	23.33	102.00	4.37
DR 92 (Check)	106	101.67	26.67	115.00	4.44
VANDANA	92	105.00	22.33	120.00	4.03
IR789787-B-22-B-B	102	88.67	21.67	104.33	2.22
IR80013-B-141-4-1	107	108.00	25.00	121.00	5.02
Shahkar (Check)	114	88.00	26.67	128.00	4.87
IR79906-B-192-2-4	111	123.67	26.67	107.00	5.39
Mean	107.70	100.40	23.63	108.57	3.84

Suitable Crop Rotations for DSR and AWD Technologies

The yield of wheat planted after non-paddy crops in Pakistan is consistently higher than that of wheat harvested from paddy fields. Puddling causes soil aggregates, capillary pores, and clay dispersion to structurally break down, which deteriorates the physical characteristics of the soil. Puddling creates a compacted layer called a plow plate that prevents water from percolating and causes temporary waterlogging, which inhibits the development and root penetration of the next wheat crop. Furthermore, the process of preparing the land for paddy fields becomes challenging and expensive due to the need to pulverize the soil by disking, harrowing, and plowing. On the other hand, aerobic rice field requires less time and money for land preparation, making it very simple and gentle. The results demonstrate that, in comparison to the crop planted after a flooded and puddled field, the wheat crop cultivated after aerobic rice showed considerably more productive tillers, spike length, total grains/spike, and grain yield (Table 10). Consequently, to preserve the productivity of the rice-wheat cropping system, improve farmer livelihoods, and protect the environment, aerobic technology must replace the present rice-producing method. Table 11 shows that the average net revenue from rice chickpeas was Rs. 57,434/ha, whereas the average net income from rice wheat was Rs. 32,104/ha. Upland crop yields are adversely damaged by anaerobic soil conditions, difficult field preparation, and insufficient crop establishment after puddled rice. In contrast to the rice-wheat or rice-mustard cycles, the rice-chickpea cropping pattern was the most lucrative and productive. However, the productivity and sustainability of wheat or pulse crops, which follow after rice, are not substantially threatened by the aerobic rice system due to its robust soil structure, tillage, and crop establishment. It is essential to expand the amount of pulses in the rice-based farming system to meet the rising population's need for them and reduce the cost of imports.

Table 10. Effect of Rice Planting Methods on Following Wheat Crop

Rice Planting Method	Plant Height (cm)	Productive Tillers (No./m^2)	Spike Length (cm)	Grains/ Spike	Grain Yield (t ha^{-1})
Conventional (transplanted and flooded)	96	226	9.34	44.56	3.76
Aerobic Rice	92	265	9.56	47.85	4.25
Percent Increase	4.16	17.5	2.3	7.4	13.0

Table 11. Aerobic Rice-Based Cropping Pattern as Tested at RRI, Dokri

Cropping Pattern	Grain Yield (t/ha)	Variable Costs (Rs. /ha)	Gross Income (Rs. /ha)	Net Income (Rs. /ha)
Rice-Wheat	Rice = 3.49			
	Wheat = 3.22	64,246	96,350	32,104
Rice-Chickpea	Rice = 4.15			

	Chickpea = 2.93	51,891	109,325	57,434
Rice-Mustard	Rice = 4.63			
	Mustard = 0.48	50,655	70,725	20,070

Suitable Weed Control and Management Strategies

The problem of weed infestation persists for rice that is dry-seeded. Apart from the periodic immersion and desiccation, aerobic soil characteristics and dry-tillage methods promote the sprouting and growth of fiercely competitive weeds, leading to 50–91% reductions in grain yield (Elliot *et al*., 1984; Fujisaka *et al*., 1993). The costliest way of weed management, which none of the farmers could afford, is manual labour. However, because there are so many new treatments on the market, chemical weed management is thought to be the least expensive method (Gupta *et al*., 2003). Pre-emergence herbicides like butachlor, thiobencarb, pendimethalin, oxadiazon, oxyfluorfen, and nitrofen have all been said to be fairly effective at controlling weeds, either when used alone or in conjunction with manual weeding (Janiya and Moody, 1988; Moorthy and Manna, 1993; Pellerin and Webster, 2004).

The 2008 findings demonstrate that one application of post-emergence herbicide (Nominee) in conjunction with hand weeding was very effective in controlling weeds in dry direct seeding rice, with a grain yield of 4.0 t/ha (Table 12). The grain yield in the untreated plots was just 0.9 t/ha. A yield of 3.8 t/ha was obtained with a single application of Nominee. There were between 30 and 297 productive tillers per square meter. There were 480–577 weeds/m^2 before the herbicide, but there were only 9 weeds/m^2 thereafter. In the rice crop that was directly sown, sedges predominated, followed by broad leaves (Table 13). The density of weeds decreased significantly following the use of pesticides and hand-weeding. Nominee, an herbicide applied after rice crop emergence, efficiently managed grasses and sedges. The weeds that were present in the direct-seeded rice crop harmed its grain production since they are exceedingly hard to eradicate by manual and cultural methods. Chemical weed management is still the most affordable and environmentally friendly method; nevertheless, it requires the usage and availability of an efficient herbicide. It has been discovered that new post-emergence herbicide formulations work well to control sedges like *Cyprus rotundus* and *Cyprus iria* as well as grasses like *Echinochloa colona* or *Echinochloa crus-galli*. It is believed that the introduction and application of herbicides like Sunstar and Nominee would make the production of direct-seeded rice in the country somewhat feasible.

Table 12. Weed Management in DSR at RRI, KSK, 2008

Treatments	Weeds/ m^2(before herbicide use)	Weeds/m^2 (after herbicide)	Plant Height (cm)	No. of productive Tillers/m^2	Panicle Length (cm)	Yield (t ha^{-1})
Nominee	570.7	24.7	110.2	257.0	26.8	3.8
Nominee + hand-weeding	549.3	9.0	103.7	296.7	28.2	4.0
Sunstar	528.7	137.7	99.5	89.7	22.5	1.7
Sunstar + hand-weeding	547.7	67.0	101.8	224.3	23.6	3.3
One-Hand weeding	526.7	44.0	101.7	218.3	24.3	2.7
Two-Hand weeding	486.3	30.7	108.8	269.3	26.4	3.3
Control	577.0	645.3	95.0	29.7	19.4	0.9
Mean	540.9	136.9	103.0	197.1	24.4	2.8

Table 13. Weed Species in DSR at RRI, KSK, 2008

Treatments	Before Herbicide Application			After Herbicide Application		
	Grasses	Sedges	Broadleaves	Grasses	Sedges	Broadleaves
Nominee	19.0	358.7	148.3	1.3	8.3	15.0

Nominee + hand weeding	22.7	382.3	146.3	6.7	25.3	35.0
Sunstar	26.7	388.7	159.3	2.0	47.7	70.0
Sunstar + hand weeding	19.7	403.3	119.3	0.3	5.3	3.3
One-Hand weeding	21.0	362.7	144.3	6.3	25.0	12.7
Two-Hand weeding	19.0	368.3	97.0	2.0	17.7	11.0
Control	19.0	454.3	103.7	23.3	476.7	145.3
Mean	21.4	388.3	131.2	8.6	86.6	41.8

Suitable Water Management Strategies for DSR and AWD

Water needed for low-land rice ranges from 1,650 to 3000 mm (Tuong and Bouman, 2001; Lampayan and Bouman, 2005). An aerobic rice production system helps to improve water productivity by preventing ongoing seepage and percolation losses, significantly reducing evaporation because there is never any standing water during the cropping season and efficiently utilizing rainfall. This also helps to prevent the concurrent loss of soil nutrients, silt, and sediments. It is evident from a comparison of the water requirements of aerobic rice systems and lowland flooded rice that the former can conserve up to 45% of the latter's water (Shashidhar, 2007). The amount of water utilized in each field and the number of irrigations were used to calculate the water usage in both aerobic and AWD rice plots. According to the statistics, the AWD-treated Basmati rice crop used 975 mm of water, as opposed to 1320 mm for the normal flooded rice crop. This represents a 35% reduction in water consumption in the AWD instance (Table 14). However, the AWD approach resulted in a somewhat lower paddy yield. Based on several previous studies, it has been shown that the AWD approach may save between 30 and 35 percent of the water used in basmati rice. The safe-AWD approach may be used on Basmati rice to prevent yield decline and provide at-par quality analysis. Although there is no yield penalty with the safe AWD technology, water savings can reach 20–23%. On farms, however, safe AWD is already used by farmers instead of drying the field at -30 kPa.

Table 14. Average Water-saving and other agronomic traits of Basmati Rice varieties with AWD and conventional puddled rice at RRI, KSK

Parameters	**AWD**	**Puddle & Flooded**
Pre-planting water use (land preparation)	130 mm	210 mm
No. of Subsequent irrigations	8	12
Total water applied	585 mm	850 mm
Rainfall water	260 mm	260 mm
Total water used	975 mm	1320 mm
Plant height (cm)	117.34	110.40
Tillers/plant	15.35	20.20
Panicle length (cm)	27.30	24.90
Paddy yield (t/ha)	3.43	3.75
Water-saving in AWD	**35.38 %**	-
Cost of Water Saving	Rs. 8,500/ha	-
Cost of Paddy Yield Difference	-	Rs. 7,000/ha
Net monitory Benefit	Rs. 1,500/ha	-

Up-scaling of Water Saving Technologies

A project on upscaling water-saving rice production technology was begun by PARC in 2009–11 with support from the Government of Pakistan, in recognition of the importance of water shortage in rice agriculture. The demonstration plots were set up at 25 sites across the three primary rice-growing districts in Punjab province: Sadhoke (district Gujranwala), Chunian (district Kasur), and Chiniot. It was also requested that the Department of Agricultural Extension assist or cooperate in this respect. Puddled, transplanted, and continually flooded rice were the typical farming practices at each site, and they were contrasted with dry-seeded rice with AWD.

135 plots overall, each measuring one acre, were created. Under the guidance of project teams, farmers tended rice plots with types Super Basmati and KSK-133, receiving all inputs (fertilizers, seed, herbicides, and pesticides) from the project team. It took a lot of effort and time to develop so many plots in different sites in such a short amount of time. The findings showed that in comparison to typical farmers' practices (1850 mm), dry-seeded rice crops utilized an average of 1410 mm irrigation water, resulting in a 25% irrigation water savings (Table 15). The Sadhoke site reported the greatest water savings on clay soil, which has a high water-holding capacity and a low percolation rate; the Chunnian site, on light-textured soil, recorded the lowest water savings. All three sites saw a 49% increase in productive tillers from dry seeding compared to transplanted rice planted in puddles; site averages varied from 388 to 451/m 2 (Table 15). These results support the findings of Wiangsamut *et al*. (2006) and Ullah *et al*., (2007), who found that dry-seeded rice generated more productive tillers than transplanted rice. The average output of rice seeded dry was 5.35 t ha-1, a 27% increase above conventional farmer practices, which yielded an average yield of 4.20 t ha-1 (Table 15). These results are also consistent with those of Ullah *et al*., (2007), Wiangsamut *et al.*, (2006), and Gangwar *et al.*, (2008), who found that dry seeding produced the maximum yield of rice. Dry seeding yielded Rs. 32,550/ha (US$ 383/ha) more than the traditional rice production method, according to the partial budget study. To improve land and water productivity as well as farmer income, dry seeding and AWD can solve the concerns of low plant density resulting in poor yield as well as labour and water shortages in the existing rice farming system. In certain fields, however, the traditional transplanted/puddled rice crop yielded a slightly higher grain yield than the dry direct sowing method. Farmers were thrilled to preserve valuable tube-well water while still receiving a substantial crop harvest. In the upcoming season, the farmers expressed interest in implementing the water-saving technique across a broader region. Dry direct planting was also used to construct baby trials at ten sites in Lower Sindh (that is, the districts of Thatta and Badin). June was the seeding month, and 50 kg of seed per hectare was utilized. The range of grain yield, 4.15 to 4.55 t/ha, was comparable to that of the control plots. Nonetheless, in comparison to conventional planting, farmers claimed to have saved three to six irrigations. Working with the Lower Sindh rice farming community was a novel experience, and the farmers showed a great deal of interest in the aerobic rice production method. They did not, however, closely adhere to the project teams' watering timetable since they believed it would significantly lower grain production.

Table 15. Average irrigation water uses and saving of dry seeded rice (DSR) compared with farmer practice at three sites

Project sites	**Irrigation water input (mm)**		**Productive tillers/m^2**		**% water saving of DSR over farmers' practice**	**% increase of productive tillers' DSR over farmers' practice**
	Puddled, transplanting	**DSR**	**Puddled, transplanting**	**DSR**		
Sadhoke (n=52)	2160	1450	287	452	33	57
Chunian (n=43)	1730	1300	235	397	25	69
Chiniot (n=40)	1680	1470	310	388	12	25
Mean	1850	1410	277	412	25	49

Table 16. Effect of aerobic and AWD technology on rice crop and yield in two districts

Technology	**Hafizabad**			**Mandi Bahuddin**		
	Productive tillers/m^2	**Grain Yield (t/ha)**	**Water Use**	**Productive tillers/m^2**	**Grain Yield (t/ha)**	**Water use**
Conventional Practice)	219.72	3.74	78	268.32	3.62	71
Dry direct seeding	352.76	4.68	57	380.39	4.29	60
% increase/ decrease over conventional	60.55	25.13	-26.38	41.77	18.51	-15.5

Note: A negative sign indicates a decrease in value

In cooperation with the Agricultural Extension Department, PARC initiated the initiative in two significant districts, Hafizabad and Mandi Bahuddin, the following year. In two districts, 398 rice fields of the super basmati kind were planted. In the district of Hafizabad, the field findings revealed that aerobic rice produced 25% more grain output than traditional rice crops, 26% more water savings, and 60% more productive tillers (Table 16). In contrast, Mandi Bahuddin had a 42% rise in productive tillers, an 18% increase in grain output, and a 15% improvement in water savings. Raising rice in nurseries, uprooting, relocating, transplanting, puddling, and continuously flooding the field are not included in aerobic rice technology. The farmers are eager to use this technology since it is incredibly productive and affordable for the upcoming rice season. In both districts, no evidence of an iron deficit was found. Zinc sulfate, however, was added to every rice field at a rate of 25 kg/ha. In both provinces, a great deal of attention was placed on farmer education to enable rice farming communities to embrace contemporary water-saving rice production practices. Farmers continue to be the key stakeholders in the rice industry and are the finest experts on any technology. Gaining the farmers' faith in new varieties or technologies hence requires meetings in the desired context. In this way, farmers' meetings were arranged with help from Agri. Extension staff throughout the rice season in some areas of Punjab and Sindh. The significant demo plots also hosted farmer's field days. Many farmers expressed a strong desire to implement DSR or AWD on their farms by visiting the demo plots. These kinds of events have shown to be highly successful in enlightening and inspiring farmers to embrace better, more creative methods of producing rice. In a local conversation, pamphlets and brochures about aerobic rice cultivation methods and AWD were printed and distributed among the farmers. It was discovered that farmers were eager to learn and use new technology, which would increase the productivity and sustainability of cropping systems based on rice. The target areas benefited greatly from disseminating water-saving rice production technology thanks to all of this.

CONCLUSION

The lack of canal water and the high expense of pumping subsurface water are making water scarcity in Pakistan a major problem for rice cultivation. A method of water-saving rice farming would assist in lessening the heavy dependency on water consumption while promoting food security and stability. Over the past five years, there has been a significant advancement in activities such as improved rice establishment techniques, weed management in DSR, promising variety seed multiplication, weed testing and evaluation, testing and evaluation of IRRI material for aerobic, rainfed-lowland, and drought, and farmers' meetings. A significant amount of important data has been collected to create a comprehensive bundle of water-saving rice cultivation technologies inside the nation. More than 59 lines have been chosen from the IRRI germplasm for additional varietal testing initiatives in Pakistan. Research experiments on the AWD system, crop establishment methods, weed management in DSR, rice-based cropping patterns, PVS, and plant sampling for soil-borne diseases have shown very positive results. Similarly, technological demonstration and dissemination operations in the target environment greatly contributed to farmers' increased trust in cutting-edge water-saving rice cultivation technologies. However, many farmers are continuing to adopt water-saving rice cultivation practices at their own expense. Additionally, the PARC launched a program to upgrade rice in five locations in Punjab and Sindh using water-saving methods. In these locations, water savings ranging from 25–32% were noted, along with a 14% increase in production above farmers' practices. Comparing the aerobic rice technology to the standard rice production method, the contribution was Rs. 33,000/ha (US$ 403). In terms of creating new information for resolving the issue of water shortage in the rice production system and enhancing the research capacity of two significant provincial rice research institutes, the IRRI project has been effective overall. Drought-tolerant varieties and water-saving technologies could save as much as Rs. 17.32 billion (US$ 211 million) in total water usage in the rice production system if they are implemented on roughly 50% of the target environment, which includes the divisions of Faisalabad, Sargodha, Multan, and Bahawalpur. Another benefit would be the significant expansion of rice areas brought about by new rice varieties and technology. Therefore, the farmers of Lower Sindh and Punjab's unconventional rice region would greatly benefit from new, creative kinds of crop establishment techniques, which would raise farm revenue and enhance their wealth and standard of living.

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