ANSF
APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
15(1), 75 - 84 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Impact of alternate wetting and drying irrigation and brown manuring on water use, weed control and yield of drum seeded rice

K. Vijay Aravinth*
Department of Agronomy, AnbilDharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli- 620027 (Tamil Nadu), India
S. Avudaithai
Department of Agronomy, AnbilDharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli- 620027 (Tamil Nadu), India
T. Ramesh
Department of Agronomy, AnbilDharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli- 620027 (Tamil Nadu), India
P. Balasubramaniam
Directorate of Natural Resource Management, Tamil Nadu Agricultural University, Coimbatore- 641 003 (Tamil Nadu), India
M. Sundar
Department of Agricultural Microbiology, AnbilDharmalingam Agricultural College & Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli- 620027 (Tamil Nadu), India

*Corresponding author. Email: johnvijaymam95@gmail.com

Article Info
https://doi.org/10.31018/jans.v15i1.4208
Received: November 10, 2022
Revised: January 21, 2023
Accepted: January 27, 2023

How to Cite
Aravinth, K. V. *et al.* (2023). Impact of alternate wetting and drying irrigation and brown manuring on water use, weed control and yield of drum seeded rice. *Journal of Applied and Natural Science*, 15(1), 75 - 84. https://doi.org/10.31018/jans.v15i1.4208

Abstract
Direct-seeded rice (DSR) is a cost-effective and environmentally friendly method of crop establishment. Weed menaces in DSR considerably reduce the yield potential, which can be addressed by effective irrigation and weed management practices. Information on the impact of various water-saving irrigations and brown manure (BM) on water use, weed studies, and the yield of drum-sown rice is very limited. A field investigation was conducted to determine the effects of alternate wetting and drying irrigation (AWDI) methods (10 cm, 15 cm dropped from FWT and farmers practices) and BM (*Sesbania* at 15, 20 and 25 kg ha^{-1}, Pretilachlor 0.45 kg ha^{-1} as PE *fb*Bispyribac Na 25 g ha^{-1} as PoE + hand weeding (HW) on 45 DAS, HW at 20 and 45 DAS, and weedy check. The results revealed that AWDI at 15 cm depletion of FWT with HW on 20 and 45 DAS increased the water use efficiency (5.3 kg ha mm^{-1}), water productivity (0.53 kg m^{-3}), water saving percentage (35.83%), and reduced the water consumption (770 mm). Continuous submergence with HW at 20 and 45 DAS significantly increased grain (4.4 t ha^{-1}) and straw yield (6.5 t ha^{-1}). At the same time, it reduced the grasses (53.3 and 58.4%) and sedges (76 and 75%), density and dry weight, respectively, over AWDI at 10 cm dropped from FWT. Thus, irrigation at 10 cm below FWT with *sesbania* BM at 20 kg ha^{-1} could be recommended for higher productivity of drum-sown rice under sodic soil conditions.

Keywords: Brown manuring, Direct seeded rice, Field water tube, Grain yield, Water use efficiency

INTRODUCTION

Rice is an important cereal crop and more than half of the world's population consumes rice as their (Cordero-Lara, 2020). The worldwide rice cultivated area was 164.2 million hectares with a production of 509.9 million metric tonnes as milled rice(Statista, 2022). India has the largest rice growing area in the world, with 43.7 million hectares, and ranks second in terms of production, with 124.3 million tonnes, with an average productivity of 27.1 q ha^{-1}. The projected population of India was 1.81 billion and thatwill surpass China as the most populous nation in the world by 2050(Indiastat, 2021).Hence, there is a need to enhance rice production. One of the biggest threats to global economic and environmental security is water shortage. More water will be diverted from agricultural usage due to rapid industrialization and urbanization. Generally, rice cultivation makes heavy use of irrigated freshwater resources. Also, in traditional rice farming, labour is needed for nursery establishment, uprooting, transportation, and transplanting, but this labour is becoming scarce during the busy season (Aslam *et al*., 2008). To get higher irrigation efficiency from limited water supply, optimum irrigation water use is a crucial issue in rice cultivation. The problem of water shortage can be solved by altering agricultural techniques, adjusting plant establishment and water management techniques. There is evidence that drum-sown rice reduces the need for labour and water. In terms of yield potential, drum-sown rice records a comparable or higher yield than transplanting rice(Bhushan *et al*., 2007). Additionally, it reduces energy and labour requirements, enables efficient water use, timely sowing of succeeding crops, and may give a higher yield(Ishfaq*et al*., 2020). For rice cultivation, several water-saving irrigation techniques have been developed. Alternate wetting and drying(AWD) approaches are more beneficial for getting the greatest advantages(Lampayan*et al*., 2015). In AWDI, an alternate cycle of saturated and unsaturated conditions is allowed, and water is drained until the soil reaches a specific moisture level. At this point, the field is re-flooded. Alternate wetting and drying reduce water requirements by 38% compared to continuous flooding(Lampayan*et al*., 2005). Deploying a field water tube in AWDI allows water usage to be controlled by up to 25% without affecting rice yield(Kulkarni, 2011).

In direct seeding with alternate wetting and drying irrigation, weeds are the primary pests that impact rice production. According to estimates, weed competition causes yield losses in rice that typically range between 40 to 60%, but they might reach 82% in DSR if weed growth is left unchecked(Chauhan and Johnson, 2011). Rice and weeds fight for the same nutrients, light, moisture, and space. Additionally, any delay in weeding increases weed biomass, which has a negative relationship with crop yield. Hand weeding is the most widely used technique to manage weeds in India and other developing nations. In addition to manual weeding, several herbicides have been designed.*Sesbania* based brown manuring is another method for reducing weed problems in DSR. Brown manuring is a no-till version of green manuring that uses selective herbicides like 2, 4-D or Bispyribac sodium to knockdown and desiccates BM plants like *sesbania* at 30 DAS(Gaire*et al*., 2013). During the growth of *sesbania*, it acts as a live mulch, and after being knocked down, plant residues left in the field act as dead mulch, thereby smothering the weeds. Furthermore, it may offer the twin benefits of increasing soil biomass and suppressing weeds because they are fast-growing species. There is limited evidence on the effects of different water-saving irrigation and brown manuring (BM) on DSR. In light of these considerations, a study was conducted to investigate the effects of various water-saving irrigation schedules and brown manuring on drum-seeded rice.

MATERIALS AND METHODS

Experimental site

A field experiment was carried out at AnbilDharmalingam Agricultural College and Research Institute, Tiruchirappalli, during the *rabi* season 2021-22, to study the effect of water saving irrigation methods and brown manuring on water use, weed control and yield of DSR under sodic soil condition. Table 1 shows the initial soil characteristics of experimental field. The experimental soil was alkaline (pH 8.7). Initial soil status was low, medium, and high in available N (Alkaline permanganate method by Asija and Subbiah, 1956), P (Colorimetric method by Olsen *et al*., 1954) and K (Flame photometer method by Stanford and English, 1949), respectively. The experimental site is located at 10° 45’ N latitude, 78° 36’ E longitude, and at an altitude of 85 m above MSL. The meteorological data collected from agricultural meteorological observatory located at AnbilDharmalingam Agricultural College and Research Institute, Tiruchirappalli revealed that the total rainfall received during the cropping season (September 2021–January 2022) was 984 mm. The mean maximum and minimum temperatures were 32.5° C and 23.2°C respectively. The mean relative humidity was 86.9% (morning) and 59.5% (evening). The mean bright sunshine hours and evaporation per day were 5.4 hrs day^{-1} and 7.4 mm day^{-1}, respectively.

Field experiment

The experiment was laid out in a split plot design with three main plots and six sub-plots, each replicated thrice. The main-plot treatments consist of irrigation after 10 cm depletion of the field water tube (M_1), irrigation after 15 cm depletion of field water tube (M_2), and irrigation after the disappearance of ponded water (M_3). The sub-plot treatments consist of brown manuringwith *sesbania* at 15 kg ha^{-1} (S_1), brown manuring with *sesbania* at 20 kg ha^{-1} (S_2), brown manuring with *sesbania* at 25 kg ha^{-1} (S_3), sequential application of PE Pretilachlor at 0.45 kg ha^{-1} followed by PoE Bispyribac sodium at 25 g ha^{-1}+ HW on 45 DAS (S_4), hand weeding at 20 and 45 DAS (S_5), and weedy check (S_6). The medium duration variety TNAU Rice TRY 3 was used as the test variety. The sowing of direct seeded rice was done in well puddled and levelled fields by using a paddy drum seeder at a row spacing of 20 cm. A full dose of P_2O_5, K_2O, and a half dose of nitrogen was applied as basal. The remaining half of the nitrogen was applied during active tillering and panicle initiation. Buffer channels were used to divide each plot so that the treatments could be maintained properly. To monitor the perched water level in the root zone, field water tubes made of perforated polyvinyl chloride (PVC) were placed in all plots except those with irrigation after disappearance of ponded water. When the plot was irrigated, the quantity of irrigation was measured by a Parshall flume installed at the inlet of the field. From 14 DAS to 10 days prior to the harvesting stage, the irrigation schedule was followed. For brown manuring purposes, *sesbania* seeds were broadcasted uniformly after sowing the rice seeds as per treatment, and Bispyribac sodium at 25 g ha^{-1} was sprayed at 30 DAS to knock down the *sesbania*.

Water use studies

The amount of irrigation water used and the actual rainfall was added together to get the overall amount of water used. During the cropping period, effective rainfall is computed as 65 percent of the total amount of rainfall(Mohanapriya*et al*., 2019).

W= ND+ Re …Eq. 1

Where

W - Total water consumed (mm)

N - Number of irrigation

D - Applied water depth for each irrigation (mm)

Re - Effective rainfall during the cropping period (mm)

The term water use efficiency refers to how much carbon is absorbed as biomass or grain produced per unit of water consumed by the crop. WUE was computed using the equation(Viets, 1962) of and expressed as kg $hamm^{-1}$.

WUE= Y/W (kg $hamm^{-1}$) …Eq. 2

Where,

Y -Grain yield (kg ha^{-1})

W - Total water used (irrigation water applied+ effective rainfall) to produce the yield (mm)

Water saving percentage was calculated by using the following formula,

Water saving % = Water supplied in flooded plot - Water supplied in treated plot / Water supplied in flooded plot x 100 ... Eq. 3

Table 1. Initial soil properties of the experimental field

Soil properties	Content
Physical properties	
Clay (%)	25.49
Silt (%)	8.42
Sand (%)	65.05
Texture	Sandy clay loam
Bulk density (g cc^{-1})	1.28
Chemical properties	
pH	8.7
EC (dS m^{-1})	0.22
ESP (%)	21.6
Available N (kg ha^{-1})	218
Available P (kg ha^{-1})	14.3
Available K (kg ha^{-1})	288.3
OC (%)	0.45

EC, Electrical conductivity; ESP, Exchangeable sodium percentage and OC, Organic carbon

Weed studies

Weed density and dry weight

Weed density and dry weight (above ground) were recorded by collecting weeds from randomly placed quadrate in the field (50 cm× 50 cm) at 40 DAS. The weed samples were sun-dried for three days and then placed in a hot air oven at 70°C for 72 hours till constant weight was recorded. Weed dry weight was recorded by using a digital balance.

Weed control efficiency (WCE) (Das and Das, 2018) and weed control index (WCI) were worked out by using following formula

WCE (%)= WDc - WDt / WDc x 100 ...Eq. 4

Where,

WDc - the weed density (no. m^{-2}) in the control plot;

WDt - the weed density (no. m^{-2}) in the treatment plot

Weed index shows the yield drop caused by weeds in comparison to weed-free plots. It can be calculated by following the formula

WI= Yield in weed free plots - yield in treatment plot / Yield in weed free plots x 100 ... Eq. 5

Various indices were calculated afterRana and Kumar (2014)

Weed persistent index (WPI)

WPI= Weed dry weight in treated plot /Weed dry weight in control plot x Weed dry $\sqrt{(x+0.5)}$ weight in control plot / Weed dry weight in treated plot ...Eq. 6

Weed management index (WMI)

WMI = % yield over control / % control of weeds ... Eq. 7

Agronomic management index (AMI)

AMI= % yield over control - % control of weeds / % control of weeds ... Eq. 8

Integrated weed management index (IWMI)

IWMI= WMI+AMI / 2 ... Eq. 9

Weed intensity (%)

WLn (%) = Weed density / Weed + crop density x 100 ... Eq. 10

Crop intensity (%)

CIn(%) = 100- Win ... Eq. 11

The harvested paddy was manually threshed plot-wise and then it was sun-dried, cleaned, winnowed and weighed separately. Grain yield was calculated at 14 percent moisture content and expressed in q ha^{-1}. The square-root transformation was used to translate data on weed density and dry weight before statistical analysis. All the data were statistically analysed following the procedure given by Gomez and Gomez (2010).

RESULTS AND DISCUSSION

Total water consumed

Effective water management is necessary for efficient irrigation water use throughout the whole growth cycle of the crop. The quantity of water needed to support crop metabolic needs and evapotranspiration requirements combined makes up consumptive water usage, including effective rainfall (Kang *et al*., 2021). The present study revealed that the recommended practice of irrigation after the disappearance of ponded water consumed more total water of 1421 mm(Table 2). It may be due to deeper percolation losses, seepage, and high water loss by evaporation which cause more frequent irrigation of the crop. Mohanapriya *et al*. (2019), reported that irrigation with continuous flooding recorded higher water consumption with more number of irrigations in transplanted rice. Data mentioned in Table. 2 showed that the lower consumption of total water was recorded under irrigation after 15 cm depletion of the field water tube (1043 mm) which was followed by irrigation after 10 cm depletion of the field water tube (1296 mm) (Table. 2). This might be due to the fact that rice roots will be able to absorb water from the saturated soil and the perched water in the rhizosphere when water depth drops below the soil surface.It results in lower evaporation losses and less frequent irrigation. Among the sub-plots, weedy check (1540 mm) recorded higher total water consumption, which was followed by brown manuring with *sesbania* at 25 kg ha^{-1} (1366 mm). Whereas lower water consumption was recorded in hand weeding and that was followed by brown manuring of *sesbania* at 20 kg ha^{-1}.

Water saving percentage

Irrigation after 15 cm of depletion of the field water tube recorded more efficient water saving percentage of 27.30% over irrigation after the disappearance of ponded water (Table 2). It was followed by irrigation after 10 cm depletion of the field water tube, which recorded a water saving percentage of 9%. Field water tube technique showed that irrigation should be timed correctly to grow rice crops with minimal use ofwater. According to Goncalves *et al*. (2021), alternate wetting and drying irrigation saved 10% irrigation water with no additional significant rice grain yield losses. In the present study, among the brown manuring practices in DSR, the higher water saving percentage (23.13%) was observed in hand weeding at 20 and 45 DAS followed by brown manuring with *sesbania* at 20 kg ha^{-1} (20.9%). The lowest water saving was recorded in the weedy check treatment (11.7%).

Water use efficiency and water productivity

Irrigation regimes have significant impacts on water use efficiency and water productivity. The amount of water used to produce one unit of grain yield is known as water productivity. The data presented in Table 3 indicated that irrigation after 15 cm depletion of field water tube registered higher WUE (3.45 kg ha-mm^{-1}) and WP (0.34

Table 2. Effect of water saving irrigation and brown manuring on total water consumption (mm) and water saving percentage on drum seeded rice

	Total water consumed (mm)*							Water saving percentage*						
Treatment	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_1	1350	1194	1407	1200	1075	1550	1296	8.54	10.70	6.20	10.78	10.42	7.19	8.97
M_2	1040	920	1190	937	770	1400	1043	29.54	31.19	20.67	30.33	35.83	16.17	27.29
M_3	1476	1337	1500	1345	1200	1670	1421	0	0	0	0	0	0	0
Mean	1289	1150	1366	1161	1015	1540		19.04	20.94	13.43	20.56	23.13	11.68	

Table 3. Effect of water saving irrigation and brown manuring on water use efficiency (kg ha-mm^{-1}) and water productivity (kg m^{-3}) in drum seed rice

	Water use efficiency (kg ha-mm^{-1})							Water productivity (kg m^{-3})						
Treatment	S_1	S_2	S_3	S_4	S_5	S_6	Mean	S_1	S_2	S_3	S_4	S_5	S_6	Mean
M_1	2.74	3.40	2.23	3.27	4.08	1.89	2.94	0.27	0.34	0.22	0.33	0.41	0.19	0.27
M_2	3.35	4.09	2.53	3.95	5.30	1.47	3.45	0.34	0.41	0.25	0.40	0.53	0.15	0.34
M_3	2.52	3.17	2.24	2.98	3.72	1.81	2.74	0.25	0.32	0.22	0.30	0.37	0.18	0.25
Mean	2.87	3.55	2.33	3.40	4.37	1.72		0.29	0.36	0.23	0.34	0.44	0.17	
	M	S	M at S	S at M				M	S	M at S	S at M			
SEd	0.021	0.043	0.071	0.074			SEd	0.005	0.003	0.005	0.006			
CD (P=0.05)	0.059	0.088	0.150	0.153			CD (P=0.05)	0.004	0.007	0.012	0.012			

kg m^{-3}). This was followed by irrigation after 10 cm depletion of the field water tube. This might be due to the intermittent irrigation schedule being able to enhance growth factors that help other physiological processes, leading to better grain yield and WUE. Due to need-based irrigation utilizing a monitoring device, such as a field water tube, and maintaining yield at an ideal level, the adoption of the field water tube irrigation technique resulted in greater WUE and WP (Isnawan*et al*., 2022).Ishfaq*et al*. (2020) reported that AWDI increased water productivity by 32% compared to conventional irrigation. Santheepan and Ramanathan (2016) also observed that AWDI at 10 cm drops of FWT from 7 DAT up to 10 prior to harvest registered highest WUE of 6.12 kg ha mm^{-1}. Conversely, our present study indicated that irrigation after the disappearance of ponded water recorded lower WUE (2.74 kg ha-mm^{-1}) and WP (0.25 kg m^{-3}). Water use efficiency and productivity werereduced when irrigation was applied using the traditional approach because of either larger water inputs or a loss in grain production.Nayaka *et al*. (2022) found that AWDI recorded significantly higher water productivity and WUE than conventional irrigation in rice. Among the sub-plots,higher WUE and WP of 4.37 kg ha-mm^{-1} and 0.44 kg m^{-3}, respectively were recorded in weed-free plot. It was followed by brown manuring with *sesbania* seed rate of 20 kg ha^{-1}. The lesser WUE (1.72 kg ha-mm^{-1}) and WP (0.17 kg m^{-3}) were recorded under unweeded control.

Weed density and weed dry weight

The major weed flora observed in experimental field was*Echinochloacolona*, *Echinochloacrusgalli*, *Cyperus difformis*, *Cyperus rotundus*and *Bergia capensis*. Sedges were dominated compared to grasses and broad leaved weeds. Water saving irrigation and weed management practices significantly influenced the weed density and dry weight of weeds over control in drum seeded rice (Tables4 and 5). Irrigation after 15 cm depletion of field water tube increased the weed density (18.7, 20.4 and 8.6 m^{-2}) and dry weight (43.4, 36.9 and 18.5 g m^{-2}), whereas irrigation after disappearance of ponded water reduced the weed density (12.6, 10.3 and 5.4 m^{-2}) and dry weight (28.2, 20.9 and 11.4 g m^{-2}) of grasses, sedges and broad leaved weeds. Weedy check recorded higher weed density (66.9, 67.5 and 35.2 m-2) and dry weight (147.3, 119.4 and 75.1 g m-2) among weed management practices. Hand weeding on 20 and 45 DAS recorded lower weed density (1.4, 2.1 and 0 m^{-2}) and dry weight (5.4, 1.6 and 0 g m^{-2}) . It was followed by brown manurig of *sesbania* at 25 kg ha^{-1}. Compared to grasses and sedges, broad-leaved weeds were effectively controlled by brown manuring practices.With respect to interaction effect of both irrigation and weed management practice, irrigation after the

Table 4. Effect of water saving irrigation and brown manuring on weed density in drum seeded rice (no. m^{-2}) at 40 DAS

Grasses								Sedges							BLW						
Treatment	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**
M_1	14.5	10.6	2.4	2.9	1.5	68	16.7	13.2	10.6	5	4.7	2.5	82.5	19.8	5.6	1.1	0	0	0	36.9	7.3
M_2	13.2	8	5.7	3.5	2.1	79.5	18.7	14.8	11.3	7.9	5.4	3.1	79.8	20.4	6.4	3.6	1.9	1.3	0	38.2	8.6
M_3	10	8.8	1.5	1.3	0.7	53.1	12.6	10.5	7.1	2.3	1.1	0.6	40.3	10.3	2	0	0	0	0	30.6	5.4
Mean	12.6	9.1	3.2	2.6	1.4	66.9		12.8	9.7	5.1	3.7	2.1	67.5		4.7	1.6	0.6	0.4	0.0	35.2	
	M		S		M at S		S at M	M		S		M at S		S at M	M		S		M at S		S at M
SEd	0.024		0.047		0.079		0.082	0.035		0.051		0.088		0.088	0.024		0.021		0.042		0.037
CD (P=0.05)	0.066		0.097		0.166		0.168	0.097		0.104		0.190		0.181	0.069		0.044		0.097		0.076

Values of SEd and CD (P=0.05) are derived from data transformation by using $\sqrt{(x+0.5)}$

Table 5. Effect of water saving irrigation and brown manuring on weed dry weight (g m^{-2}) in drum seeded rice at 40 DAS

Grasses								Sedges							BLW						
Treatment	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**
M_1	34.1	21.8	12.3	9.2	6.5	149.3	38.9	27.5	19.3	13.1	7.5	2.0	136.5	34.3	14.1	4.1	0	0.0	0.0	79.0	16.2
M_2	36	22.2	13.1	11.5	7.0	170.2	43.3	29.3	21.6	15.5	11.7	2.4	140.8	36.9	16	4.5	4	2.4	0.0	83.9	18.5
M_3	22.3	15	3.4	3.3	2.7	122.5	28.2	23.8	12.1	6.3	1.9	0.5	81.0	20.9	6.3	0	0	0.0	0.0	62.3	11.4
Mean	30.8	19.7	12.7	8.0	5.4	147.3		26.9	17.7	11.6	7.0	1.6	119.4		12.1	2.9	1.3	0.8	0.0	75.1	
	M	S	M at S	S at M				M	S	M at S	S at M				M	S	M at S	S at M			
SEd	0.056	0.054	0.102	0.094				0.063	0.064	0.119	0.110				0.039	0.051	0.089	0.088			
CD (P=0.05)	0.156	0.111	0.232	0.192				0.176	0.130	0.269	0.226				0.109	0.104	0.196	0.180			

Values of SEd and CD (P=0.05) are derived from data transformation by using

Table 6. Effect of water saving irrigation and brown manuring on weed control efficiency (%) in drum seeded rice

20 DAS								40 DAS							60 DAS						
Treatment	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**Mean**
M_1	35.3	52.0	64.1	85.8	92.7	0.0	55.0	82.2	88.1	96.1	95.9	97.9	0.0	76.7	79.2	85.4	92.6	96.1	98.3	0.0	75.3
M_2	36.8	51.2	58.6	83.8	92.5	0.0	53.8	82.6	88.4	92.2	94.8	97.4	0.0	75.9	79.0	84.2	90.0	94.7	98.0	0.0	74.3
M_3	42.4	59.9	68.5	92.2	95.4	0.0	59.7	81.9	87.2	96.9	98.1	99.0	0.0	77.2	77.5	84.3	91.7	97.7	99.3	0.0	75.1
Mean	38.2	54.4	63.8	87.3	93.5	0.0		82.2	87.9	95.0	96.3	98.1	0.0		78.6	84.6	91.4	96.1	98.5	0.0	

Table 7. Effect of water saving irrigation and brown manuring on weed impact assessment indices

Treatment combination	WI	WPI	WMI	AMI	IWMI	WIn (%)	CIn (%)
M_1S_1	15.6	1.1	1.64	0.64	1.14	57.0	43.0
M_1S_2	7.5	1.1	1.65	0.65	1.15	48.2	51.8
M_1S_3	28.5	1.24	1.18	0.18	0.68	32.1	67.9
M_1S_4	10.5	0.82	1.38	0.38	0.88	20.1	79.9
M_1S_5	0.0	1.11	1.52	0.52	1.02	9.8	90.2
M_1S_6	33.1	1	0	0	0	86.5	13.6
M_2S_1	14.6	1.08	2.19	1.19	1.69	57.7	42.3
M_2S_2	7.9	1.04	2.18	1.18	1.68	50.7	49.3
M_2S_3	26.4	1	1.62	0.62	1.12	39.3	60.7
M_2S_4	9.3	0.71	1.86	0.86	1.36	25.5	74.5
M_2S_5	0.0	1.05	2.02	1.02	1.52	11.3	88.7
M_2S_6	49.5	1	0	0	0	86.6	13.4
M_3S_1	16.7	0.97	1.58	0.58	1.08	50.5	49.5
M_3S_2	5.2	0.87	1.62	0.62	1.12	41.6	58.4
M_3S_3	24.9	1.01	1.21	0.21	0.71	27.3	72.7
M_3S_4	10.3	0.69	1.35	0.35	0.85	9.6	90.4
M_3S_5	0.0	1.25	1.49	0.49	0.99	3.2	96.8
M_3S_6	32.4	1	0	0	0	82.0	18.1

WI-Weed index; WPI-Weed persistence index; WMI-Weed management index, AMI-Agronomic management index; IWMI-Integrated weed management index; WIn-Weed intensity, CIn-Crop intensity

disappearance of ponded water with hand weeding on 20 and 45 DAS reduced weed density (0.7, 0.6 and 0 m $^{-2}$) and weed dry weight (2.7, 0.5 and 0 g m^{-2}).Complete removal of weed species from treatment plots by hand weeding reduced the weed density and weed dry weight. Barla *et al*. (2021) found that manual weeding at 15, 30, 45 and 60 DAS registered lower weed density and weed dry weight in DSR grown in Ranchi.

Weed control efficiency

The effectiveness of weed management directly relates to crop yield. Weed control efficiency was significantly influenced by irrigation regimes (Table 6). Among water saving irrigation regimes, irrigation after the disappearance of ponded water recorded maximum weed control efficiency of 59.7%, 77.2% and 75.1% at 20, 40 and 60 DAS, respectively. Increasing the level of irrigation levels hindered weed emergence and weed density (Juraimi*et al*., 2009). After 15 cm depletion of field water tube, Irrigation recorded lower WCE than other irrigation regimes. Among the sub-plots manual weeding at 20 and 45 DAS recorded higher WCE which was followed by sequential application of pre-emergence pretilachlor *fb* post emergence bispyribac sodium 25 g ha^{-1}at 20 DAS. Within the brown manuring practices higher seed rate of *sesbania* (25 kg ha^{-1}) registered maximum WCE. This might be due to the initial suppression of weeds providing favourable environment for rice growth and development (Sen *et al*., 2021).

Weed impact indices

Higher value of weed impact indices indicates effective weed control. Since higher weed density and lower grain yield, weedy check treatments recorded higher weed index in all the irrigation regimes (Table 7). Brown manuring practices of *sesbania* sown at 20 kg ha^{-1} recorded a lower weed index. The lower weed persistence index was noticed under PE pretilachlor *fb*bispyribac sodium 25 g ha^{-1} at 20 DAS. Higher weed management index, agronomic management index and integrated weed management index were recorded in *sesbania* brown manuring at 20 kg ha^{-1} in entire water saving irrigation regimes. Higher weed intensity (38.3%) was observed under unweeded control; manual weeding twice at 20 and 45 DAS recorded lower weed intensity. Rana *et al*. (2017) found that pendimethalin + mulching+ hand weeding recorded lower weed persistence index and higher integrated weed management index in turmeric. The present study indicated that hand weeding at 20 and 45 DAS registered higher crop intensity (91.9%) followed by sequential application of pre-emergence pretilachlor *fb* bispyribac sodium 25 g ha^{-1} at 20 DAS (81.6%). Among the brown manuring practices, *sesbania* at 25 kg ha^{-1} recorded higher cropping intensity (67.1%).

Grain and straw yield

Yield is a crucial measure of the advantage of DSR

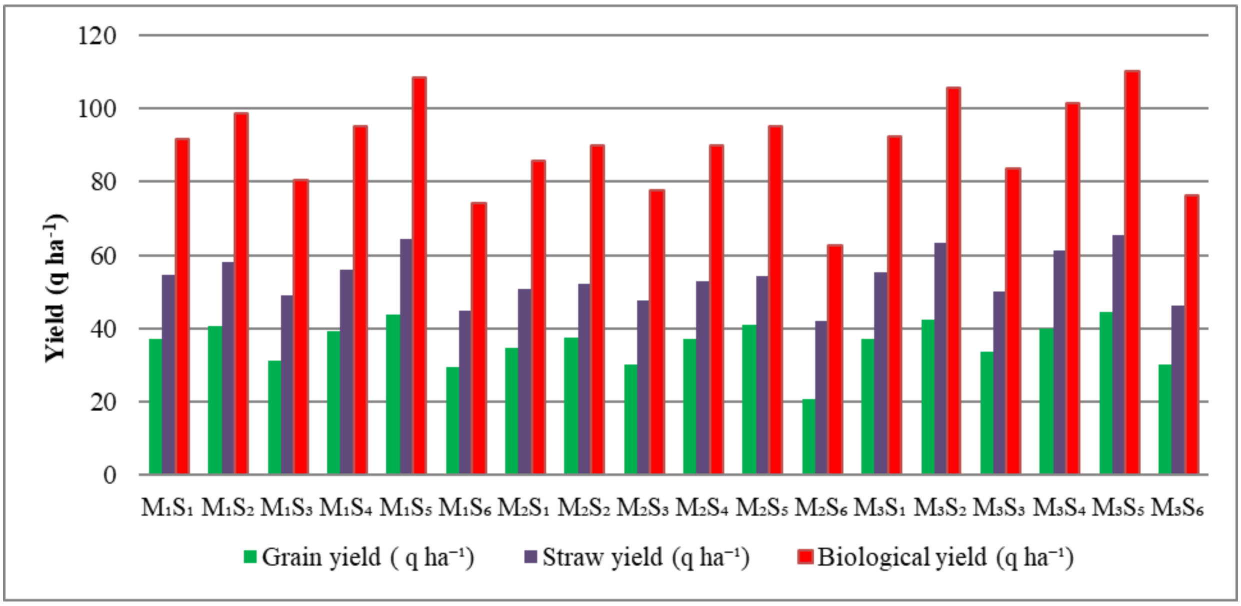

Fig. 1. *Effect of water saving irrigation and brown manuring on grain, straw and biological yield (q ha^{-1}) of DSR*

influenced by irrigation treatments and brown manuring practices. Significantly higher grain, straw and biological yields (38.0, 56.9 and 94.9 q ha$^{-1,}$ respectively) were registered with irrigation after the disappearance of ponded water (Fig. 1). Sandhu *et al*. (2021) reported that irrigation given after one day of disappearance of water recorded higher grain and straw yield. Kumar *et al*. (2006) also showed that irrigating the summer rice daily produced comparatively higher grain and straw yield. However, the present study reported that it was comparable with irrigation after 10 cm depletion of field water tube, which recorded higher grain, straw and biological yields of 37, 54.4 and 91.3 q ha$^{-1,}$ respectively. Reduced weed growth, improved aeration, and improved root proliferation to absorb more water and nutrients may be responsible for greater grain filling and higher grain yield under AWD. As a semi-aquatic plant, rice has some adaptability and plasticity to water stress, and irrigation applied at specific critical growth periods satisfies the physiological water needs of rice. Additionally, to boost soil fertility and create more important plant available nutrients to favour rice growth, AWD provided the root system with enough oxygen to speed up soil organic matter mineralization and slow down soil N mobilization (Mote *et al*. (2017). The lowest grain, straw and biological yield (33.5, 50 and 83.4 q ha^{-1}, respectively), were obtained with irrigation after 15 cm depletion of water at the field water tube.

Different weed management practices had a significant impact on rice grain, straw and biological yield. With regard to sub-plots, weed free treatment registered higher grain, straw and biological yield (42.6, 61.4 and 104 q ha^{-1} respectively). Among the brown manuring practices, BM with *sesbania* at 20 kg ha^{-1} recorded significantly higher yield (40.1 q ha^{-1}) and it was on par

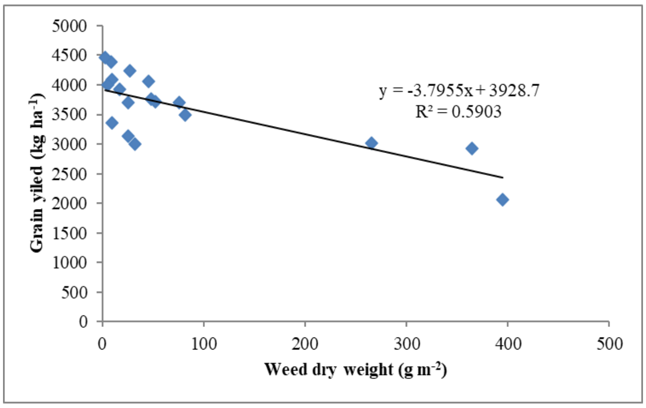

Fig. 2. *Relationship between weed dry weight at 40 DAS and grain yield of rice*

with PE Pretilachlor at 0.45 kg ha^{-1} *fb* PoE Bispyribac sodium at 25 g ha^{-1} plus HW on 45 DAS (39.14 q ha^{-1}). After being knocked down by bispyribac sodium, the BM reduced early weed flushes by space capture and late-emerging weeds through surface dead mulch and greater yield in the BM was partly caused by better soil conditions(Sen *et al*., 2020). Kumar *et al*. (2020) reported that *sesbania* co-culture in DSR reduced the weed infestation as well as significantly increased the grain and straw yield. The present study indicated that lower grain, straw and biological yield were obtained under an unweeded control plot. Interaction between main and sub-plot treatments revealed that irrigation after the disappearance of ponded water with weed-free plot resulted in higher grain and straw yields. It was statistically on par with irrigation at 10 cm depletion of field water tube with weed-free treatment and AWDI with BM of *sesbania*at 20 kg ha^{-1}. Alternate wetting and drying saved water input without significant loss of yield. Mote *et al*. (2017) reported that AWDI with weed control made by two-hand weeding recorded higher rice grain and straw yield.

Grain yield was negatively correlated with dry weed weight at 40 DAS (Fig. 2). The coefficient of determination between grain yield and weed dry weight was 0.590 at 40 DAS. The regression analysis results revealed that with every unit increase in dry weed weight (g m-2) there was a 3.79 kg ha^{-1} decrease in rice yield. This might be due to weed interference decreasing the crop biomass and its subsequent partitioning into the grains. Pooja and Saravanane (2021) indicated that rice grain yield of direct-seeded rice has a negative linear relationship with weed dry weight.

Conclusion

This study concluded that irrigation at 10 cm depletion of field water tube recorded reduced overall water usage, with water saving percentage of 27.29 % compared to irrigation after the disappearance of ponded water for rice. Also, higher water use efficiency and water productivity were recorded without a reduction in grain and straw yield over irrigation after the disappearance of ponded water. The higher WCE and weed impact indices recorded in manual weeding and sequential herbicide application. Though hand weeding gave a higher grain yield, from an economic point of view, BM with *sesbania* at 20 kg ha^{-1} will be a better option, followed by PE pretilachlor at 0.45 kg ha^{-1}*fb* and PoE bispyribac sodium at 25 g ha^{-1} with HW on 20 and 45 DAS. Hence, it could be concluded that adopting alternate wetting and drying irrigation by 10 cm depletion of field water tube along with BM with sesbania at 20 kg ha^{-1} is considered the best method in both grain yield and water saving points of view.

ACKNOWLEDGEMENTS

We are grateful to AnbilDharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, for providing field experimental facilities.

Conflict of interest

The authors declare that they have no conflict of interest.

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