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Enhancing Water Use Efficiency and Yield of Un-puddled Transplanted Basmati Rice (*Oryza sativa* L.) through Green Manuring and Irrigation Scheduling

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Abstract

The declining water table, deteriorating soil health, and low water use efficiency are major challenges to the sustainability of rice-based cropping systems. The study on water-use efficiency and yield of un-puddled transplanted basmati rice (UPTR) (*Oryza sativa* L.) under green manuring and irrigation scheduling was conducted at Khalsa College, Amritsar, during the *kharif* season in 2024. The experiment was arranged in a split-plot design, with three green manuring treatments in the main plot *i.e.,* control (G_0), green manuring with *dhaincha* (G_1), and with cowpea (G_2), and five irrigation schedules in sub-plot, *i.e.,* $I_{0:}$ puddled transplanted rice (PTR) + 15 days ponding + alternative wetting and drying (AWD), I_1 (UPTR+ 15 days ponding + AWD), I_2 (UPTR+irrigation at 3mm CPE), I_3 (UPTR+irrigation at 5mm CPE), and I_4 (UPTR+irrigation at 7mm CPE) and replicated thrice. Higher growth and yield parameters and economics were observed in $G_{1,}$ followed by $G_{2,}$ and the lowest were in G_0. Among irrigation schedules, I_2 showed the highest growth attributes, grain yield (7570 kg ha^{-1}), biological yield (18680 kg ha^{-1}), and economics, followed by I_1 and I_0. Wider irrigation intervals (I_3 and I_4) reduced growth and yield attributes. Water productivity was the highest in I_2 and I_1. Treatments I_0 and I_1 remain at par in grain yield, but water consumption in I_0 was higher, indicating water conservation in I_1 without reduction in yield. Interactions between green manuring and irrigation scheduling show that the combinations of green manures with I_2 at UPTR improve water use efficiency and water productivity.

Keywords: Water use efficiency, UPTR, PTR, CPE and AWD

Introduction

Rice is the staple food for more than half of the world's population. Rice (*Oryza sativa* L.) belongs to the Poaceae family and the Bambusoideae sub-family. Over 90 per cent of the world's rice is produced in Asia. India leads the world with an average annual production of approximately 150 million metric tonnes, followed by China with 145.3 million metric tonnes (USDA, 2025). Mainly, three states produce nearly 36 per cent of India's total rice, 1378.25 lakh tonnes from 478.3 lakh ha area. Telangana (12.24%) followed by Uttar Pradesh (11.60%) and West Bengal (11.38%) (DES, 2025). Punjab ranks fourth with a total production of 214.26 lakh tonnes from an area of 31.79 lakh ha during 2023-24 (PAU, 2025).

With declining ground water levels, rice sustainability is dwindling (Dhillon and Mangat, 2018). Punjab's 75 per cent of land is under rice cultivation, which requires 140 to 160 cm of irrigation water (Humphreys *et al*., 2010; Dhanda *et al*., 2022). PTR method of rice cultivation is very common in Punjab. The ill effects of this method challenge the sustainability of rice through soil physical, chemical, and biological properties. In addition, it also contributes to global warming through methane gas emissions. In contrast, UPTR, direct seeding of rice (DSR), and system of rice intensification (SRI) have emerged as promising alternative aerobic methods that save irrigation water, improve soil health, increase groundwater recharge, are environmentally friendly, and economically viable (Kaur and Singh, 2017). The soil environment in un-puddled transplanting rice remains similar to that of direct-seeded rice and has the potential for labour saving, reduced water use, reduced methane emissions, resolution of edaphic conflicts, and decreased crop maturity period (Balarajan *et al*., 2025). In unpuddled transplanting similar to the SRI technique of rice establishment, young-age nursery can be transplanted without mortality (Uphoff, 2024). Further, alternative to ponding of water AWD method of irrigation reduces water consumption while sustaining crop production. Studies show that AWD technique uses less water than the traditional method of continuous flooding (Brar *et al*., 2018). In north India sufficient turnover period between wheat and basmati rice provides a window for *in situ* green manuring of legume crops. Green manures like *Sesbania*, being leguminous in nature, can add a substantial amount of nitrogen required for rice, as well as adding organic matter to maintain soil fertility and improve the water-holding capacity of soil, and green manures extract nutrients from deeper layers, thereby letting the succeeding crop extract nutrients from the surface layers (Pramanik *et al*., 2004). Reduction in the use of nitrogen fertilizers and their risks of leaching are additional benefits of green manuring. *Dhaincha*, a leguminous green manuring crop, has the capacity to fix atmospheric nitrogen, reduce bulk density, and increase water-stable aggregates and total pore space by the addition of organic matter (Boparai *et al*., 1992). Taking the above points into consideration, this investigation was carried out to identify an appropriate combination of irrigation scheduling with crop establishment method and green manuring practice for the development of a sustainable and resource-efficient rice production system.

Materials and Methods

The experimental study was carried out during the *kharif* season *in* 2024 at Khalsa College, Amritsar, Punjab, which is located at a latitude of 31.63° N, longitude 77.87° E, and 234 m above sea level. The maximum temperature of 40.81°C was recorded during the 29th standard meteorological week of July, and the minimum temperature of 18.57°C was recorded during the 43rd standard meteorological week of October, 2024. The total rainfall during the crop season was recorded as 563.3 mm. The soil in the experimental field has a sandy loam texture, pH 8.2, electrical conductivity 0.29 mhos cm^{-2}, organic carbon 0.36% (low), available nitrogen 192 kg ha^{-1} (low), phosphorus 17 kg ha^{-1} (medium), and potassium 265 kg ha^{-1} (medium).

A split-plot design was used for the experiment, with three replications. The experiment comprises three green manuring treatments: G_0 (Control), G_1 (*Dhaincha*) and G_2 (Cowpea) in the main plot, and five irrigation schedules: I_0 (PTR+ 15 days ponding + AWD), I_1 (UPTR+ 15 days ponding + AWD), I_2 (UPTR+ irri. at 3mm CPE), I_3 (UPTR+ Irr. at 5mm CPE), and I_4 (UPTR+ IRR. at 7mm CPE) in subplot *kharif* rice Pusa Basmati 1692 (*Oryza sativa* L.), was grown following the package of practices except the treatment selected.

Green manuring crops were sown on 25 May; two irrigations were applied as per requirement and incorporated at 45 days after sowing. Nursery of Pusa Basmati 1692 was sown on the 10th of June after seed treatment. Seedlings of 25 days were uprooted on the 11th of July for transplanting at a spacing of 20×15 cm. In control plots (G_1), the recommended dose of urea (54 kg acre^{-1}) was applied in two equal splits at 21 and 42 days after transplanting. In G_1 and G_2 treatments, 75% of the recommended doses of urea were applied (40.5 kg ha^{-1}). Zinc sulfate heptahydrate (21% Zn) was applied at 25 kg acre^{-1}. Irrigations were applied according to the irrigation treatments. Periodic and final data were recorded andanalysed for different indices, *i.e.*

Harvest index: Harvest index was computed using the formula given below;

$$\text{Harvest Index} = \frac{\text{Economic yield (kg ha}^{-1})}{\text{Biological yield (kg ha}^{-1})} \times 100$$

Amount of irrigation water applied from transplanting to harvesting (mm): Irrigation water applied from transplanting to harvest of crop per irrigation (IW) was calculated by multiplying the discharge rate (Q) by the time taken (T) for irrigating the plots and dividing by the area of the plots (A). The total amount of irrigation water during the growing season was calculated by summing the total amount of irrigation water applied during each irrigation in mm. It was calculated in mm. The discharge rate was 8.5 litre/sec, fixed for a particular water source.

$$\text{IW} = \left(\frac{\text{Q X T}}{\text{A}} \right)$$

Total water input (mm): The total water expense was calculated as the sum of irrigation water applied to the nursery, main field, plus total rainfall received during the crop season. It was expressed in mm.

Water productivity (kg grain/mm): Water productivity was calculated by dividing grain yield (kg) by the amount of total water applied (mm). It is expressed as kg grain/mm of water.

$$\text{Water productivity} = \frac{\text{Grain Yield (kg)}}{\text{Total water input (mm)}}$$

Cost of cultivation (Rs ha^{-1}): Cost of cultivation for each treatment was calculated using the cost of different agronomic practices and inputs used in a particular treatment, respectively.

Gross return (Rs ha^{-1}): To calculate gross return, grain yield was multiplied by the market price.

Gross return = (Grain yield × Market price) + (Straw yield × Market price)

Net return (Rs ha^{-1}): Net returns of different treatments were calculated by subtracting the total cost of cultivation from the gross return.

Net return = Gross return – Total cost

B: C Ratio: B:C ratios for different treatments were calculated by dividing the total cost of cultivation by the gross return.

B:C ratio = Gross return / Total cost

Statistical analysis of observations was carried out using OPSTAT software developed by CCS HAU, Hisar. The critical difference (CD) value at a 5 per cent level of significance (*i.e.,* p=0.05) was calculated for comparing the treatments.

Results and Discussion

Yields and harvest index

The data shown in **(Table 1)** revealed that the highest grain (6710 kg ha^{-1}), straw (10270 kg ha^{-1}), and biological yield (16980 kg ha^{-1}) were recorded under *dhaincha* incorporation (G_1), which was statistically higher than control(G_0) but at par with cowpea incorporation(G_2). This may be due to the beneficial effects of Green manures on nitrogen availability and water-holding capacity. Improved nutrient availability during vegetative and reproductive phases was also observed by Gao *et al*., (2023). Increased plant height, leaf area index, effective tillers m^{-2}, number of filled grains per panicle, dry matter accumulation, which contributes directly to grain, straw, and biological yield were also reported by Duhan and Singh, (2002). Similar results were observed with the green manure effect on yield by Irin *et al.,* (2020), Song *et al.,* (2024), and Kumar *et al*., (2025).

Among irrigation schedules, I_2 produced the highest grain (7570 kg ha^{-1}), straw (11110 kg ha^{-1}), and biological yield (18680 kg ha^{-1}), which was statistically higher than I_3 and I_4. In contrast, it was at par with I_1 and I_0. The higher yield under I_2 was attributed to the greater soil moisture availability, which enhanced nutrient uptake, leaf area, photosynthetic rate, tiller survival, assimilates translocation to grain, and grain filling (Kaur and Sharma, 2022). But UPTR with 5 and 7 mm CPE irrigation (I_3 and I_4) showed the lowest grain yields as delayed irrigation caused water stress. Similar results were reported by Sandhu and Mahal

(2014) and Brar *et al*., (2021) about the reduction in yield caused by delayed irrigation.

The harvest index (HI) does not significantly vary with green manuring and irrigation scheduling. This was due to similar behaviour in biological and grain development. Kumar *et al.,* (2025) also reported similar findings, stating that green manure enhanced total biological yield without significantly affecting the partitioning of assimilates between grain and straw. In irrigation scheduling, the highest harvest index (40.5%) was reported under UPTR +irrigation at 3 mm CPE (I_2), which was statistically at par with I_0 and $I_{1,}$ which were significantly higher than I_3 and I_4 (un-puddled transplanting with 5 and 7 mm CPE irrigation). Nayak *et al*., (2020) also reported similar results.

Table 1: Effect of green manuring and irrigation scheduling on grain yield, straw yield, biological yield, harvest index, total water input, and water productivity (kg grain mm^{-1}) of basmati rice

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest Index (%)	Total water input (mm)	Water productivity (kg grain mm^{-1})
Main plot (Green manuring)						
G_0 (Control)	5920	9540	15460	38.2	1828	3.24
G_1 (*Dhaincha*)	6710	10270	16980	39.5	1750	3.83
G_2 (Cowpea)	6490	9940	16430	39.5	1760	3.69
C.D.(0.05)	306.1	334	714.8	NS	-	0.16
Sub plot (Irrigation scheduling)						
I_0 (Puddled + 15 days ponding +AWD)	6890	10880	17770	38.7	1851	3.79
I_1 (Un-puddled+ 15 days ponding +AWD)	6962	10490	17452	39.9	1830	3.85
I_2 (At 3mm CPE)	7570	11110	18680	40.5	1870	3.85
I_3 (At 5mm CPE)	5525	8960	14485	38.1	1720	3.28
I_4 (At 7mm CPE)	4920	8140	13060	37.6	1625	3.18
C.D. (0.05)	282.7	951	927. 5	2.0	-	0.19
Interaction (I×G)	NS	NS	NS	NS	-	0.34
Interaction (G×I)	NS	NS	NS	NS	-	0.32

Irrigation water applied from transplanting to harvest

The data presented in **(Table 1)** show that the control treatment (1828 mm) had the highest total water input, followed by G_2 (1760 mm), and the lowest in G_1 (1750 mm). This difference is due to high organic matter, which affects the moisture-retaining ability of soil in *dhaincha* and cowpea incorporation. In another study, cowpea required more water input than *dhaincha* due to less plant biomass production (Yin *et al*., 2025). In case of irrigation scheduling, the highest total water input was recorded in I_3, *i.e.,* 1870 mm, followed by I_0 PTR), *i.e.,* 1851 mm, and I_2 (UPTR with 15 days of ponding in AWD), *i.e.,* 1830 mm, and the lowest in irrigation at 7 mm CPE (1625 mm) I_4. Kaur *et al.,* (2024) also reported similar results. The data presented in **(Table 2)** show the interaction between green manuring and irrigation scheduling. The combination of green manure and un-puddled transplanting with irrigation at 3 mm CPE recorded the highest total water input, *i.e.,* 1915 mm, and the lowest under *dhaincha* and cowpea incorporation under un-puddled transplanting with irrigation at 7 mm CPE (1600 mm) as per irrigation numbers.

Table 2: Total water input to basmati rice as influenced by the interaction between green manuring and irrigation scheduling

Green manuring × Irrigation scheduling	Total water input (mm)					
	I_0 (Puddled + 15 days ponding+ AWD)	I_1(Unpuddled + 15 days ponding+ AWD)	I_2 (At 3 mm CPE)	I_3 (At 5 mm CPE)	I_4 (At 7 mm CPE)	**Mean**
G_0 (Control)	1905	1880	1915	1765	1675	1828
G_1 (*Dhaincha*)	1810	1800	1845	1695	1600	1750
G_2 (Cowpea)	1840	1810	1850	1700	1600	1760
Mean	1851	1830	1870	1720	1625	

Water productivity

The water productivity (WP) significantly varied among the green manuring and irrigation scheduling shown (**Table 1**). The highest WP was recorded under G_1 (3.83 kg grain mm-1), which was statistically significant from the G_0(3.24 kg grain mm-1) but at par with cowpea incorporation G_2 (3.69 kg grain mm^{-1}). Green manures enhance the water retention capacity of soil, improve the physical properties of soil due to the addition of organic matter. In irrigation scheduling, the highest WP was observed under I_1 and I_2 (3.85 kg grain mm^{-1}), followed by I_0 (3.79 kg grain mm^{-1}), $I_{3,}$ and the lowest was in I_4. This trend may be due to higher grain yield in these treatments. Nayak *et al*., (2016) and Kumari *et al*., (2018) also reported higher WP under such an irrigation schedule. The data presented in **(Table 3)** show interactions between green manuring and irrigation scheduling. The highest water productivity was observed under the combination of G_1 and I_2 (4.06 kg grain mm^{-1}) and the lowest under control and I_4 (2.68 kg grain mm^{-1}).

Table 3: Water productivity of basmati rice as influenced by the interaction between different green manuring and irrigation scheduling

Green manuring × Irrigation scheduling	Water productivity (kg grain mm^{-1})					
	I_0 (Puddled + 15 days ponding + AWD)	I_1 (Unpuddled + 15 days ponding+ AWD)	I_2 (At 3mm CPE)	I_3 (At 5 mm CPE)	I_4 (At 7 mm CPE)	**Mean**
G_0 (Control)	3.65	3.69	3.51	2.69	2.68	3.24
G_1 (*Dhaincha*)	3.93	4.02	4.06	3.66	3.49	3.83
G_2 (Cowpea)	3.81	3.83	3.98	3.49	3.37	3.69
Mean	3.79	3.85	3.85	3.28	3.18	
Interaction (I×G)	0.34					
Interaction (G×I)	0.32					

Economic Analysis

The highest gross returns and net returns were observed under G_1, and the highest benefit: cost (B:C) ratio was observed under G_0 (**Table 4**). Among the irrigation schedules, the highest gross returns, net returns, and B:C ratio were reported under I_2 followed by $I_{1,}$ $I_{0,}$ I_3 and $I_{4,}$ suggesting that un-puddled transplanting can be a more economically viable and resource-efficient practice without significantly compromising yield.

Table 4: Effect of different green manuring and irrigation scheduling on economic analysis of basmati rice

Treatments	Cost of cultivation (Rs ha^{-1})	Gross returns (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
Main plots (Green manuring)				
G_0 (Control)	44,222	207,098	162,876	3.68
G_1 (*Dhaincha*)	48,645	226,711	178,065	3.66
G_2 (Cowpea)	50,895	222,711	171,815	3.38
Sub plots (Irrigation scheduling)				
I_0 (Puddled + 15 days ponding+ AWD)	51,275	236,888	185,613	3.62
I_1 (Un-puddled+ 15 days ponding+ AWD)	47,415	238,719	191,303	4.03
I_2 (At 3mm CPE)	48,540	259,075	210,535	4.34
I_3 (At 5mm CPE)	46,672	190,310	143,637	3.08
I_4 (At 7mm CPE)	45,702	169,208	123,505	2.70

Conclusion

Based on the present investigation, it is evident that the growth and yield attributes were higher in G1(*dhaincha*), which were statistically at par with G_2 (cowpea). In terms of irrigation scheduling, I2 (3mm CPE) resulted in the best performance across growth, yield parameters and yield. The un-puddled treatment achieved a higher benefit: cost (B: C) ratio than the puddled treatment, indicating that un-puddled transplanting is a more economically viable and resource-efficient practice.

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