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Performance of alternate wetting and drying technique of irrigation scheduling of paddy in Ludhiana district of Punjab

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Abstract

Paddy cultivating areas often face challenges of escalating water scarcity, necessitating sustainable alternatives to conventional continuous flooding (CF). Alternate Wetting and Drying (AWD) is considered as a promising irrigation strategy that balances productivity with resource conservation. This study evaluates the efficacy of AWD in comparison to CF over three consecutive *Kharif* seasons (2020-2022) in Ludhiana district, Punjab, India. Sixty field demonstrations across multiple locations revealed that AWD significantly reduced irrigation frequency by approximately 16%, with an average irrigation water saving of 936 m³/acre during paddy season. Total irrigation water used under AWD averaged 5,168 m³/acre, which equates to 15.3% reduction compared to CF (6,104 m³/acre). Notably, AWD maintained grain yield at levels statistically comparable to CF, with mean yields of 29.1 q/acre and 28.8 q/acre, respectively. Agronomic parameters including tiller count, plant height (cm), and panicle length (cm) showed minimal variation between treatments, indicating no substantial physiological stress under AWD. Irrigation water productivity improved consistently under AWD, rising from 0.47 kg/m³ (CF) to 0.56 kg/m³ (AWD), reflecting enhanced efficiency in irrigation water use. These results corroborate previous findings suggesting that moderate soil drying cycles in AWD has a potential, as water-saving practice suitable for paddy growing regions facing increasing pressure on freshwater resources. Its integration into mainstream rice cultivation strategies can contribute significantly to sustainable intensification.

Keywords: Alternate wetting and drying, continuous flooding, yield, water saving, irrigation water efficiency

Introduction

Global warming and dwindling water resources pose significant threats to the sustainability of rice production and global food security. Achieving high yields in irrigated systems demands substantial water inputs as production of one kilogram of rice grain consumes an estimated 2,500 liters of water, nearly one third of the world's available freshwater is being used in production of rice crop (Bouman, 2007) ^[1]. In Asia, roughly half of the region's freshwater is used irrigate paddy (Kukul *et al.* 2004). Traditional continuous flooding (CF), the predominant cultivation method, exacerbates water scarcity, prompting the need for alternatives like alternate wetting and drying (AWD), which is a water-saving, ecofriendly and economically viable irrigation system. This method significantly reduces water use without compromising rice yields, making it a sustainable alternative to conventional flooding techniques. AWD involves three main phases to optimize water use in paddy cultivation. First is the initial period of shallow flooding viz 15 days post transplanting. During this period, maintenance of shallow water levels in the field helps seedlings recover from transplant shock and suppresses weed growth. Second is the period of controlled

ponding which is from heading to flowering stage. Since this growth phase is highly sensitive to water stress and demands high water uptake, shallow ponding during this is maintained to support rapid crop development. Remaining growth period of paddy in AWD is the period of intermittent drying. During this period, field is allowed to dry for two days after water naturally recedes in the field or lost through evaporation before reapplying irrigation. AWD is also called intermittent irrigation, as it allows the soil to dry for 2 days before re-flooding. The threshold of 2 days after receding of water not cause any yield decline since the roots of the paddy are still able to take up water from the perched groundwater and almost saturated soil above the water table (Bouman *et al.*, 2007) ^[2]. Therefore, AWD aims at maintaining soil moisture rather than continuous submersion, which reduces water consumption by flooding fields only after the disappearance of ponded water. Additionally, AWD helps mitigate methane emissions from rice fields (Setyanto 2018) ^[17]; a major contributor to greenhouse gas emissions in agriculture, while also reducing production costs for farmers through lower water and energy inputs (Lampayan *et al.* 2015) ^[9]. Thus, AWD presents a sustainable alternative to conventional flooding,

addressing water scarcity and environmental concerns while maintaining productivity.

Uppal *et al.* (1991)^[23] and Patel (2000)^[14] found that irrigating rice fields two days after disappearance of ponded water during the vegetative stage resulted in higher grain yields. AWD or maintaining saturated soil conditions with a thin water layer in paddy can lead to reduction in irrigation water usage by 40-70% compared to conventional continuous flooding, while maintaining comparable crop yields. Research studies (Chaudhary, 1997)^[4] evaluating intermittent irrigation in rice cultivation were conducted across six locations in India; Pusa, Madhepura, Pantnagar, Ludhiana, Hissar, and Kota, indicated that rice yields under intermittent irrigation were generally comparable to those achieved with conventional continuous flooding. However, the intermittent irrigation method resulted in slightly reduced yields compared to traditional practices at Hissar and Pantnagar. In a study at Hyderabad, Shantappa *et al.* (2014)^[19], noticed that significantly lower quantity of water was applied in alternate wetting and drying (1151mm) and saturation (960 mm) than continuous submergence (1433 mm). Lampayan *et al.* (2015)^[9] comparing AWD irrigation with traditional farmer practices across multiple countries, revealed that AWD irrigation method did not cause any significant reduction in crop yields overall. 66% of the studied sites (16 out of 24 participating farms) demonstrated yield improvements under AWD and required substantially less water input than conventional practices, with water savings ranging from 17% to 38% across all trial sites. Rejesus *et al.* (2011)^[15] also found that use of intermittent irrigation methods helped to save around 38% of water compared to conventional flood irrigation, while maintaining similar crop yields. AWD technique lowers the frequency of irrigation events and enhances the efficiency of water use (Mallareddy *et al.*, 2023)^[12]. Several other studies have also shown that when compared to either CF or FP, AWD irrigation method increases grain yield (Yang *et al.*, 2009; Wang *et al.*, 2014).^[26, 24] However, in some studies, AWD either does not alter (Yao *et al.*, 2012; Linquist *et al.*, 2015; Shaibu *et al.*, 2015; Howell *et al.*, 2015)^[27, 10, 18, 6] or slightly lowers yield (Sudhir-Yadav *et al.*, 2012; Shaibu *et al.*, 2015)^[20, 18]. AWD technique contributes to lower greenhouse gas emissions and offers better management of diseases in crop (Ishfaq *et al.*, 2020)^[11]. AWD practice enhances root aeration and significantly reduces methane emissions, which are major environmental concerns associated with continuously flooded rice systems (Bouman, 2007)^[1]. Studies by Richards and Sander have shown that AWD not only conserves water but also enhances nutrient uptake efficiency, contributing to sustainable rice production. Furthermore, LaHue *et al.* (2016)^[8] observed that AWD could improve soil structure over time by reducing waterlogging-induced degradation, though long-term effects on soil health require further investigation.

Materials and Methods

A total of 60 demonstrations on AWD in paddy were conducted by KVK Ludhiana during three years; *Kharif* 2020, 2021 and 2022 at 20, 30 and 10 locations respectively in Ludhiana district. Ludhiana is located in Punjab's central

plains, falling within India's trans-Gangetic agro-climatic zone. This semi-arid, subtropical area experiences distinct seasonal variations; hot and dry summers (April-June), hot monsoon conditions (July-September), autumn months (October-November), and cold winters (December-February). The region receives approximately 755 mm of annual precipitation, with the southwest monsoon accounting for nearly 70% of rainfall between July and September. Winter months (December-February) typically see minimal precipitation from northeast monsoons, contributing marginally to the annual total. The soils at locations under study were of medium soil fertility with sandy loam texture. For the study, two one-acre plots were selected at each study location, one for alternate wetting and drying (AWD) irrigation and other for continuous flooding (CF) as the control treatment. The source of irrigation was the electric or diesel engine operated tubewell at all the locations. At each plot number of irrigations applied were recorded. To calculate the irrigation water used, the first irrigation for puddling in each treatment was assumed to be 12 cm and following irrigation after transplanting were assumed as 6 cm each. Full package of agronomic practices recommended by Punjab Agricultural University, Ludhiana was adopted at the study sites. The performance of the AWD in terms of grain yield and irrigation water productivity was compared with the check *i.e* continuous flooding. The primary data on grain yield and agronomic traits in AWD and CF plots was recorded. The irrigation water use efficiency was calculated by the formula [Massey *et al.* 2022]^[13].

$$IWUE = Y/IW$$

Where, IWUE = Irrigation water use efficiency (kg m^{-3}), Y = Grain yield (kg acre^{-1}), IW = Irrigation water applied (m^3) to the crop

Results and Discussion

Grain yield: The study compared paddy grain yield (Table 1) under continuous flooding and alternate wetting and drying over three *Kharif* seasons (2020-2022). Mean grain yield was slightly higher under AWD (29.1 q/acre) than CF (28.8 q/acre), indicating that AWD does not reduce productivity. This can be attributed to improved growth and better development of root and shoot in AWD irrigation systems (Yang and Zhang, 2010; Thakur *et al.*, 2011)^[25, 22]. Periodic drying phases in AWD enhance root proliferations, resulting in efficient absorption of both water and nutrients, while simultaneously increasing leaf area expansion and accelerating leaf growth rates (Dobermann and Fairhurst, 2000; Kirk, 2004)^[5, 7]. These combined physiological advantages ultimately contribute to improved crop productivity and yield potential. Results in the study also align with previous research showing that moderate soil drying in AWD can maintain or even improve yields while saving water (Carrijo *et al.*, 2017)^[3]. The consistency across seasons suggests AWD's reliability as a water-efficient alternative to CF. These findings support AWD's adoption in paddy growing regions, where sustainable practices are crucial for maintaining rice production.

Table 1: Effect of alternate wetting and drying on the yield, number of irrigations and yield contributing parameters of rice during *Kharif* 2020-2022

	Grain yield (q/acre)		No of tiller per meter		Plant Height (cm)		Panicle length (cm)	
	CF	AWD	CF	AWD	AWD	CF	AWD	CF
Kharif 2020	28.1	28.3	269.7	263.1	101	100.6	26.9	26.8
Kharif 2021	29.4	29.8	267.2	264.1	100.7	100.6	27.1	26.9
Kharif 2022	28.9	29.3	263.4	261.4	101	101.3	26.5	26.4
Mean	28.8	29.1	266.8	262.9	100.9	100.8	26.8	26.7

Agronomic traits: The study also evaluated the effects of alternate wetting and drying (AWD) and continuous flooding on agronomic traits across three *Kharif* seasons (2020-2022). CF produced marginally more tillers (266.8) than AWD (262.9), possibly due to constant moisture availability promoting tiller formation. However, the difference was minimal, indicating that AWD does not severely restrict tillering. Both treatments showed nearly identical plant heights in CF (100.9 cm) and 100.8 cm in AWD, suggesting that moderate soil drying in AWD does not stunt growth. Panicle length remained consistent as 26.8 cm in AWD and 26.7 cm in CF. The results revealed subtle but notable differences between the two irrigation practices. Similar results have also been reported by Uppal *et al.*, 1991^[23] and Patel, 2000^[14].

Irrigation parameters: The results in table 2 demonstrated that CF consistently required more irrigations than AWD across all three years. During *Kharif* 2020, CF needed 25.8 irrigations, whereas AWD required only 21.2. Similarly, in *Kharif* 2021 and 2022, CF required 23.3 and 24.2 irrigations, respectively, compared to AWD's 20.1 and 20.3. On average, in CF 24.4 irrigations were applied to paddy crop per season, while in AWD only 20.5 irrigations were applied the farmers, indicating a reduction of approximately 16%. This demonstrates that AWD is a more efficient irrigation strategy, reducing the frequency of irrigation water application because CF consistently consumed more water than AWD across all three years (2020, 2021, and 2022). During *Kharif* 2020, CF used 6,432 m³/acre of water, while AWD required only 5,328 m³/acre, saving 1,104 m³/acre per season. Similarly, in *Kharif* 2021, CF consumed 5,832 m³/acre compared to AWD's 5,064

m³/acre, and in *Kharif* 2022, CF used 6,048 m³/acre while AWD required 5,112 m³/acre. AWD led to substantial water savings of 1,104 m³, 768 m³, and 936 m³, across three *Kharif* seasons from 2020-2022, respectively. On average, CF utilized 6,104 m³/acre of water per season (paddy), whereas AWD used 5,168 m³/acre, resulting in a 15.3% reduction in water usage under AWD. Consequently, irrigation water use efficiency (IWUE) under AWD increased by 20.5%, 18.0%, and 18.8% compared to CF, during *Kharif* 2020, 2021 and 2022 respectively, with mean values rising from 0.47 kg m⁻³ (CF) to 0.56 kg m⁻³ (AWD). These findings suggest that AWD enhances irrigation water-use efficiency while maintaining crop yield, likely due to reduced unproductive water losses such as evaporation and percolation. The consistent improvement across three consecutive seasons underscores the reliability of AWD as a water-saving strategy in paddy cultivation. The enhanced water productivity under AWD can be attributed to the controlled irrigation strategy, which minimizes unproductive water losses such as evaporation, seepage, and percolation Bouman (2007)^[2], while maintaining sufficient soil moisture for crop growth. These findings align with previous studies by Lampayan *et al.* (2015)^[9] who reported that AWD could reduce water use by 15-30% without significantly affecting yield. Similarly, Carrijo *et al.* (2017)^[3] conducted a meta-analysis of AWD studies and found an average water savings of 23% with only a marginal yield reduction (5-10%) in most cases. The consistent improvement across three consecutive seasons reinforces AWD as a reliable water-saving strategy in paddy cultivation.

Table 2: Effect of alternate wetting and drying on the water productivity during *Kharif* 2020-22

	No. of irrigations		Irrigation water used (m ³ /acre)		Irrigation water use efficiency (kg m ⁻³)	
	CF	AWD	CF	AWD	CF	AWD
Kharif 2020	25.8	21.2	6432	5328	0.44	0.53
Kharif 2021	23.3	20.1	5832	5064	0.50	0.59
Kharif 2022	24.2	20.3	6048	5112	0.48	0.57
Mean	24.4	20.5	6104	5168	0.47	0.56

Conclusion

The findings clearly show the benefits and positive potential of AWD as an alternative to CF, as AWD maintains yield while reducing water input; a crucial factor for sustainable agriculture. The minimal differences in agronomic traits suggest that AWD does not impose physiological stress severe enough to hinder crop performance. Reduced irrigations and better irrigation water use efficiency in AWD also stresses that AWD technique holds great promise as water-saving technology that can help to address water scarcity in the rice growing areas. However, the success of AWD depends on proper implementation, including

monitoring soil moisture and maintaining optimal drying phases to avoid yield penalties. Sudhir-Yadav *et al.* (2011)^[20] also emphasized that excessive drying could stress the crop, highlighting the need for site-specific adaptation.

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