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Water productivity of 2 rice genotypes grown in different soil textures and irrigated through continuous flooding and alternate wetting and drying irrigation methods

B. Wiangsamut[1*], T. Lafarge[2] and T.C. Mendoza[3]

[1]Department of Crop Production and Landscape Technology, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok Chanthaburi Campus, Khao Kitchakut, Chanthaburi 22210, Thailand, [2]Senior Ecophysiologist of the Crop and Environmental Sciences Division, International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines, [3]Professor of Crop Science, College of Agriculture, University of the Philippines Los Baños, College, Laguna 4031, Philippines

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Abstract This study was conducted to quantify water use, grain yield and water productivity of 2 rice genotypes in 5 soil textures grown under the conventional continuous flooding irrigation method (CF), alternate wetting and drying irrigation methods (AWD20 and AWD30). The field experiments were established in two sites (Barangay Pance in Ramos and Barangay Dapdap in Paniqui) in the province of Tarlac, Philippines during the dry season (DS) from November of 2007 to March of 2008; and were laid out in randomized complete block design with treatments in split-plot arrangements, replicated four times. The three irrigation methods occupied the main plots while the two rice genotypes (PSB Rc80 and IR78386H) occupied the subplots.
The water productivities (WPi) of hybrid rice genotype (IR78386H) under CF were 1.36, 1.04, 0.30, 0.40, and 0.39 kg grain m^{-3} water while for the inbred (PSB Rc80) were 1.35, 1.03, 0.24, 0.32, and 0.46 kg grain m^{-3} water in clay loam, clay, loam, sandy loam, silt loam soils, respectively. The WPi under AWD20 were higher than CF in sandy loam and loam soils. Grain yield under AWD20 increased by 7.3% and WPi increased by 78% due to the reduction in water used by 38.4% in sandy loam soil. The irrigation water use (WUi) under AWD20 to produce 1 kg of unmilled rice was 2,140L. The inbred genotype was more adapted to AWD20 irrigation method than the hybrid genotype. Savings in water use under AWD30 were about 53% in sandy loam and 40% in silt loam soil textures but grain yields of 2 rice genotypes decreased by 40% under sandy soil condition and reduced by about 50% in silt loam. AWD30 irrigation method is not advisable to be adopted by rice farmers in the light-textured soils.

Keywords: water use, grain yields, water productivity, continuous flooding irrigation method (CF), alternate wetting and drying irrigation methods (AWD20, AWD30), rice genotypes, soil textures

* **Corresponding author**: B. Wiangsamut; **e-mail:** timbancha@yahoo.com

Introduction

Rice (*Oryza sativa* L.) is the major staple food in Asia. Of the roughly 530 million ton per year rice produced globally, 90–92% is produced and consumed in Asia, where it provides 35–80% of total calorie intake (IRRI, 1997). However, to keep up with population growth and income-induced demand for food in most low-income Asian countries (Hossain, 1997), it is estimated that rice production has to be increased by 56% over the next 30 years (IRRI, 1997). In Asia, more than 50% of all water used for irrigation is used to irrigate rice (Barker *et al*., 1999). About 75% of the global rice volume is produced in the irrigated lowlands (Maclean *et al.*, 2002). Freshwater, however, is becoming increasingly scarce. In many Asian countries, per capita availability declined by 40–60% between 1995 and 1990, and is expected to decline further by 15–54% over the next 35 years (Gleick, 1993). The main reasons are population growth, increasing urban and industrial demand, and decreasing availability because of pollution, (chemicals, salt, silt) and resource depletion (e.g. groundwater mining). Food security of Asian depends largely on the irrigated rice production system (Guerra *et al*., 1998). The term water-saving irrigation techniques have been introduced (Guerra *et al*., 1998). Because of the increasing demand for food combined with the increasing scarcity of water, rice producers have to save water and increase water productivity and to produce more rice with less water (Lu *et al*., 2000).

However, decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase the water productivity of rice (Guerra *et al*., 1998) and alternate wetting and drying should be used (Tabbal *et al.*, 2002).

During the 1990s, IRRI and national researchers tested several water-saving technologies such as saturated soil culture, saturated soil and soil drying, and alternate wetting and drying (AWD) in farmers' fields. These methods have been reported to increase water productivity by reducing water input by up to 35% compared with continuous flooding, but grain yield decreased (Borell *et al.*, 1997; Lu *et al.*, 2000).

Water use was up to 5,000 liters to produce 1 kg of unmilled rice grain (Cantrell and Hettel, 2004). Because of increasing water scarcity, there is a need to develop alternative irrigation systems that require less water but stable or increasing grain yield. One option is identify rice genotypes that will adapt on specific location and soil textures. Hence, this study was conducted using 2 rice genotypes (hybrid and inbred) and grown in clay loam, clay, loam, sandy loam, and silt loam soils under continuous flooding and 2 alternate wetting and drying (AWDs) method of irrigation.

Specifically, the study aimed to quantify water use, grain yield and water productivity of 2 rice genotypes under continuous flooding irrigation method (CF), alternate wetting and drying irrigation method when the perched water table is 20 cm below the soil surface (AWD20), and alternate wetting and drying irrigation method when the soil moisture tension at 15 cm below soil surface reaches 30 kilopascal (AWD30) in sandy loam, silt loam, loam, clay loam, and clay soil textures.

Materials and methods

Location, Time of the Study, Nursery and Field Techniques

Five field experiments were established in two sites: Barangay Pance in Ramos and Barangay Dapdap in Paniqui, both in the province of Tarlac, Philippines during the dry season (DS) from November of 2007 to March of 2008. The two field experiments representing sandy loam soil and silt loam soil textures were laid-out in Barangay Dapdap while the three field experiments representing loam soil, clay loam and clay soil textures were established in Barangay Pance. Soil samples were gathered from the top soil layer (0 – 10 cm) before the land preparation for the soil textural analyses and other chemical and physical properties in each site (Table 1). Textural class, organic carbon (C), pH, P, K, Mg, Ca, and CEC were then determined, also for each site. The percent sand texture derived from the five experimental sites was determined.

Table 1. Soil physical and chemical properties in the experimental sites

Parameters	**Irrigation treatment plots**						
	CF	AWD30	CF	AWD30	AWD30	AWD30	AWD30
	sandy loam		silt loam		Loam	clay loam	clay
	0-19 cm	0-19.7cm	0-17.3 cm	0-18 cm	0-12.5 cm	0-8 cm	0-10 cm
Soil chemical properties							
Available (mg/kg)							
Phosphorus (P)	9.0	4.3	6.5	4.9	11.0	2.8	3.1
Exchangeable (meq/100g)							
Sodium (Na)	0.331	0.320	0.822	0.875	1.19	4.80	5.44
Potassium (K)	<MDL	<MDL	0.168	0.192	0.092	0.372	0.370
Calcium (Ca)	3.45	4.66	9.85	10.5	4.93	16.0	24.3
Magnesium (Mg)	2.49	3.25	8.11	8.38	2.69	10.0	17.3
General							
pH	6.1	7.1	7.0	7.5	6.6	7.6	7.2
Organic Carbon or OC	0.286	0.393	0.900	0.415	0.736	1.310	1.810

(%)							
Cation Exchangeable Capacity or CEC (meq/100 mg)	5.51	6.96	16.5	16.4	7.49	24.8	42.1
Soil physical properties (textures)							
Clay (%)	9	10	17	18	13	34	63
Silt (%)	19	22	54	58	48	42	34
Sand (%)	72	68	29	24	39	24	3

MDL; Method Detection Limits

Adequate land preparation and recommended seedling preparations were adopted. Twenty nine-day old seedlings were pulled out from the seedling bed for transplanting on the same day in CF, AWD20, and AWD30 plots with hill spacing of 20 cm x 20 cm, two seedlings per hill, corresponding to 25 hills m^{-2} or 100 plants m^{-2}. Missing plants in the planted hills were replanted within 10 days after transplanting.

The field experiments were laid out in randomized complete block design (RCBD) with treatments in split-plot arrangements, replicated four times. The three irrigation methods that occupied the main plot treatments were: (1) continuous flooding (CF) irrigation method; (2) alternate wetting and drying (AWD20) irrigation method and, 3) alternate wetting and drying (AWD30) irrigation method. The rice genotypes that occupied the subplot treatments were PSB Rc80, an inbred rice genotype, and IR78386H, which is hybrid rice (Table 2).

Table 2. Summarized characteristics of the two rice genotypes used in the study

Name of rice genotype	**Types of irrigation**	**Grain yield (t ha^{-1})**	**Crop duration (day)**	**Plant height (cm)**	**Tiller number per plant**	**Remarks**
PSB Rc80	CF	7.0	118	92	14	Sensitive* -released
	AWD	6.8	121	99	21	
IR78386H	CF	N	n	n	N	
	AWD	N	n	n	N	

*Sensitive was the parameter used for how the rice genotype responded to water stress.
n = no data

Climate Station and Meteorological Data

The climate station was located in Barangay Pance, about 8 kilometers away from the other experiment site in Barangay Dapdap. Climate data were collected throughout the experimental period (Table 3). The average solar radiation was 17.3 MJ m^{-2}. The atmospheric temperature ranged from 28.3 – 32.5ºC. Wind speed ranged from 1.26 – 1.93 m s^{-1}. Percent relative humidity ranged from 74.4–83.8%. The total monthly rainfall ranged from 0.42–1.57 mm with the total amount of precipitation of 2.08 mm from land preparation to harvesting in Barangay Dapdap while it ranged from 5.40–182.70 mm with the total amount of precipitation of 332.80 mm.

Table 3. Meteorological data during the experimental period from November 2007 to March 2008

Month/year	**Solar radiation (mj m^{-2})**	**Temperature (°c)**	**Wind speed (m s^{-1})**	**Relative humidity (%)**	**Amount of rainfall (mm)**	
					Barangay Pance	Barangay Dapdap
November2007☼	9.5	28.3	1.26	- *	56.20	0.00
December 2007	18.6	32.0	1.62	-	9.00	0.00
January 2008	18.7	31.3	1.78	-	79.50	0.42
February 2008	18.3	30.4	1.93	74.4	5.40	0.09
March 2008╬	21.4	32.5	1.76	83.8	182.70	1.57

☼ Data on 23-30 November 2007
╬ Data on 1-26 March 2008
* Data were missing due to the measurement equipment were broken

Measurement of Field Water Depth, Soil Moisture Tension, and Ground Water Table Depth

In each location, two tensiometers were installed in the subplots of IR78386H (one tensiometer per subplot) and another two in the subplots of PSB Rc80 (one tensiometer per subplot), both with a depth of 15 cm from the soil surface under AWD30 irrigation; away from both sides of the dike for four rows of the transplanted rice plants. The reading was taken twice a day, at 0700H and 1300H, and data were recorded in kilopascal (kPa). No tensiometers were installed in the subplots of the two rice genotypes under CF and AWD20 irrigation methods.

Porous cylinders (or porous Polyvinyl Chloride (PVC) pipes with 60 cm long, 2.5 inches in diameter with 2 mm holes surrounding its surface) were installed in the subplots of the two rice genotypes under AWD20 irrigation only: two cylinders in the hybrid rice plots, and the other two in the inbred rice plots. These cylinders were buried at a depth of 40 cm below soil surface to measure the perched water table depth but left 20 cm above the soil surface to monitor the ponded water depth. The PVC readings were done together with the tensiometer readings at 0700H daily. One stick gauge per subplot (the marked scale can be read from 0 to 15 cm which is similar to a ruler) was installed to monitor the level of standing water and the irrigation water supplied in all the subplots (CF, AWD20 and AWD30) of the experiment.

Four porous cylinders (or porous PVC pipes with 150 cm long, 2.5 inches in diameter with 2 mm holes surrounding its surface) were used for the two locations of the experiment. Two porous PVCs per site were installed on the dike at the two opposite corners of each experimental site, with a depth of 130 cm below soil surface to measure the ground water table but 20 cm was left above the soil surface. Ground water table depth was measured by exerting a floating meter stick in the side of the mouth of the PVC then was read at its tip. This reading was done daily at 0700H throughout the rice growing period. Data were recorded and computed for the depth of ground water table in each site for the entire growing period.

Irrigation Water Management Practices and Measurement of Irrigation Water Input

In the CF treatment plots, the standing water was maintained between 1 and 5 cm above soil surface determined by the installed staff gauges (stick gauges). The standing water was imposed from the first day of transplanting until just about 2 weeks before harvest. The irrigation water was pumped from the irrigation canal using the small water pump with 2-horse power connecting with a flow meter for the value reading of the irrigation water input for each of the transplanted plot. Data were recorded at each time irrigation is supplied in cubic meter water per square meter area (m^3 water m^{-2} area).

In the AWD20 plots, standing water was maintained between 1 and 5 cm above soil surface on the first 4 – 5 days after transplanting, for the plant to recover from transplanting shock. Rice plants were then subjected to alternate wetting and drying soil moisture condition known as AWD20 cycle. For every cycle, irrigation water was supplied when the level of the perched water table was at 20 cm below soil surface, monitored through the installed porous PVCs' reading. In each time of irrigation, the ponded water level was at 5 cm above soil surface. This AWD20 cycle was made until the plants flowered, and then the standing water was maintained until just about two weeks before harvest. Irrigation water was supplied using the water pump connected to a rubber hose and a flow meter, similar with those in CF plots. The amount of water input was then recorded in the unit of cubic meter water per square meter area (m^3 water m^{-2} area).

In the treatment of AWD30 plots, standing water (between 1 and 5 cm) was maintained at 5 cm above the soil surface during the first 4–5 days after transplanting, for plant to recover from physiological shock. Then, plants were exposed to alternate wetting and drying soil moisture conditions known as AWD30 irrigation or AWD30 cycle, until the plants flowered. Irrigation water was applied when the soil moisture tension reached 30 kilopascal (kPa), or 0.3

bars soil moisture tension, as per reading from a tensiometer that was installed at 15 cm depth from the soil surface. The standing water was imposed again during flowering stage until just about two weeks before harvest.

Water use was measured from the period of land preparation, nursery plots, transplanting up to harvesting. The application of irrigation water and measurement of its water input were mentioned earlier for CF, AWD20 and AWD30 plots.

Fertilizer Management

Nitrogen (N), Phosphorus (P), Potassium (K) and Zinc (Zn) fertilizers were first applied together by broadcasting in the transplanted rice fields at a rate of 40 kg N ha^{-1} from Urea $(NH_4)_2SO_4$ or (45-0-0), 50 kg P ha^{-1} from Solophos or (0-18-0) or superphosphate, 50 kg K ha^{-1} from Muriate of potash or (0-0-60), and 5 kg Zn ha^{-1} from Zinc Sulphate ($ZnSO_4$) on the transplanting date. The first, second, and third topdressings of N fertilizer were based on the chlorophyll meter (SPAD) readings with a threshold value of 36 to adjust the N application for Urea (45-0-0). Four hills per plot were randomly chosen and the SPAD meter was used to read in three positions (base, middle, and top leaf portions) of the second fully-expanded younger leaf to obtain an average value of chlorophyll content. These readings were made every second week in all the plots. When the SPAD readings are above number 36, N presence was enough in the leaves therefore application is not needed. If readings were below 36, plants would require N fertilizer, hence N was applied. The first topdressing of fertilizer was done at 20 days after transplanting (DAT) at a rate of 40 kg N ha^{-1} for all plots in the sandy loam soil texture, except in AWD30 plot of the hybrid rice which was later applied (23 DAT) when irrigation water was first supplied.

The same rate of N fertilizer was applied for all the transplanted plots (CF, AWD20 and AWD30) in silt loam, loam, clay loam, and clay soil textures at 28, 26, 30 and 30 DAT, respectively. The second application was at a rate of 40 kg N ha^{-1} for all plots of the hybrid rice (IR78386H) at 41, 40, 42, 44 and 48 DAT in sandy loam, silt loam, loam, clay loam, and clay soil textures, respectively. While for all plots of the inbred rice (PSB Rc80), the same rate of fertilizer was applied at 44, 47, 42, 44, and 48 DAT in sandy loam, silt loam, loam, clay loam, and clay soil textures, respectively. The last application was at a rate of 20 kg N ha^{-1} for all plots of the IR78386H in sandy loam, silt loam, loam, clay loam, and clay soil textures at 49, 48, 49, 49, and 49 DAT, respectively. It was at 56, 56, 57, 59, and 59 DAT in sandy loam, silt loam, loam, clay loam, and clay soil textures, respectively, for all plots of the PSB Rc80. At the end of the experiment, applications for all kinds of fertilizers were the same for all plots (CF, AWD20 and AWD30) of the five sites. The total amount of nitrogen fertilizer applied was 140 kg N ha^{-1}; nitrogen could be sufficient for the regular plant growth.

Grain Yield Measurement

The harvest area of 2 m^2 (2 m x 1 m) corresponding to 50 hills (or 10 hills x 5 hills or 2 m^2) per subplot and was harvested at physiological maturity stage. These samples were threshed to obtain the whole grains of each subplot, and were adjusted to 14% moisture content. Consequently, the unit was converted into ton per hectare (t ha^{-1}).

Water Productivity Measurement

Water productivity (WPi) was calculated by computing the ratio of the total grain weight (or grain yield) per unit of ground area to the total water use per unit of ground area. The total water use is the amount of water applied to the crop from seed sowing to harvest plus the water used for land preparation.

Statistical Analysis

Data on all parameters were analyzed separately in each experimental site based on split-plot design using statistical analysis system (SAS) program. Treatments means were compared using the Least Significant Difference (LSD) at the 0.05 probability level.

Results and discussions

Water use and grain yields of the 2 rice genotypes in sandy loam, silt loam, loam, clay loam, clay soils under continuous flooding and AWDs method of irrigation

Continuous flooding irrigation method (CF) required the highest quantity of irrigation water use (WUi) at 23,974 m^3 ha^{-1} (yield at 6.42 t ha^{-1}) in sandy loam soil, followed by 20,771 m^3 ha^{-1} in silt loam soil (yield at 7.38 t ha^{-1}), and 16,669 m^3 ha^{-1} in loam soil (yield at 7.09 t ha^{-1}) (Tables 4a and 4b). The lowest quantity of WUi was used in clay and clay loam soils at 7,025 m^3 ha^{-1} (yield at 7.27 t ha^{-1}) and at 5,163 m^3 ha^{-1} (yield at 7 t ha^{-1}), respectively. Grain yields under CF in sandy loam, silt loam, loam, clay, and clay loam soils did not vary significantly; although grain yield slightly increased by about 7.1% (0.5 t ha^{-1}) under AWD20 in clay loam compared with CF. Between the 2 genotypes, grain yields of hybrid genotype (IR78386H) were slightly higher in clay and clay loam soils under CF and AWDs (AWD20 and AWD30) compared with the inbred genotype (PSB Rc80) although not statistically significant.

Regardless of irrigation methods, there was differential water use between the 2 genotypes in the different soil textures. The PSB Rc80 when grown in the heavy-textured soils (clay and clay loam soils) required an average quantity of 4,937 m^3 ha^{-1} of WUi from land preparation until harvest to obtain an average grain yield of 6.88 t ha^{-1}, while an average of 15,619 m^3 ha^{-1} of irrigation water was used to produce a grain yield at 5.7 t ha^{-1} in sandy loam, silt loam, and loam soils.

The IR78386H grown in clay and clay loam soils required an average amount of 5,251 m^3 ha^{-1} of WUi starting from land preparation until harvest to obtain the grain yield of 7.47 t ha^{-1}; while in sandy loam, silt loam, and loam soils, it required an average of 15,335 m^3 ha^{-1} to produce grain yield at 5.68 t ha^{-1}. Grain yields were not significantly different in all soil textures although the highest yield was obtained in silt loam soil at 8.16 t ha^{-1}.

Regardless of genotypes and rainfall, irrigation water use was significantly lesser in the clay loam to clay soils (5,163 m^3 ha^{-1} and 7,025 m^3 ha^{-1}, respectively) as shown in Table 4b. This could be attributed to the following: 1) clay and clay loam soils retained water (water above soil surface) for a longer period of time due to the reduced loss of water through percolation which was due to less sand and low number of visible micro-pores; 2) the clay to clay loam soils had shallower groundwater table depth at 10 to 45 cm, and 15 to 42 cm, compared to 60 to 145 cm (sandy loam), 53 to 95 cm (silt loam), 55 to 85 cm (loam) during the dry months of November 2007 to March 2008. The IR78386H and PSB Rc80 had 50 cm maximum rooting depth from the ground surface. It was observed that the root distribution of IR78386H (hybrid rice) and PSB Rc80 (inbred rice) were always above the ground water table for the whole rice growing period in sandy loam, silt loam, and loam soils. The groundwater in clay and clay loam soils remained within the root zone for the whole rice growing period which explains why rice plants did not suffer any water deficit conditions under AWD30 irrigation method. The shallow ground water table depth could explain why the perched water table never reached 20 cm below soil surface under the designed AWD20 irrigation method and likewise, the soil moisture tension never reached 30 kPa (0.3 bars) under AWD30 irrigation method in clay loam and clay soil textures.

Between the two genotypes, growth duration could also explain their difference in water use. The PSB Rc80 had 10 days longer growth duration than of IR78386H in sandy loam soil, leading to about 15% higher WUi. The longer growth duration contributed to the higher amount of irrigation water loss through the percolation and seepage in the light-textured soils (sandy loam, silt loam, and loam soils) rather than the heavy-textured soils (clay and clay loam soils). In loam soil, the growth duration of PSB Rc80 was longer by nine days in AWD30 compared with CF.

Table 4a. Irrigation water use, grain yield, water use per kg grain in 3 irrigation methods for the hybrid and inbred genotypes in sandy loam, silt loam, and loam soils

		Sandy loam				Silt loam				Loam			
Irrigation Method	**Rice Genotype**	Water use for irrigation water only or WUi (m^3 ha^{-1})	Grain yield (t ha^{-1})	Water used (liter)/ 1 kg unmilled rice	Water productivity (Wpi) (kg grain m^{-3} water)	Water use for irrigation water only or WUi (m^3 ha^{-1})	Grain yield (t ha^{-1})	Water used (liter)/1 kg unmilled rice	Water productivity (Wpi) (kg grain m^{-3} water)	Water use for irrigation water only or WUi (m^3 ha^{-1})	Grain yield (t ha^{-1})	Water used (liter)/ 1 kg unmilled rice	Water productivity (Wpi) (kg grain m^{-3} water)
CF	IR78386H, hybrid rice	23,087	6.83^{a}	3,380	0.30^{a}	20,630	8.16^{a}	2,528	0.40^{a}	17,600	6.92^{a}	2,543	0.39^{a}
	PSB Rc80, inbred rice	24,861	6.00^{a}	4,143	0.24^{a}	20,912	6.59^{b}	3,173	0.32^{a}	15,737	7.26^{a}	2,168	0.46^{a}
	Mean	23,974	6.42^{v}	3,762	0.27^{x}	20,771	7.38^{v}	2,851	0.36^{v}	16,668	7.09^{v}	2,356	0.43^{v}
AWD20													
	IR78386H, hybrid rice	12,925	6.88^{a}	1,874	0.53^{a}	17,748	6.01^{a}	2,953	0.34^{a}	12,227	4.97^{b}	2,460	0.41^{a}
	PSB Rc80, inbred rice	16,605	6.90^{a}	2,406	0.42^{a}	18,356	6.89^{a}	2,664	0.38^{a}	11,421	5.51^{b}	2,073	0.48^{a}
	Mean	14,765	6.89^{v}	2,140	0.48^{v}	18,052	6.45^{v}	2,809	0.36^{v}	11,824	5.24^{w}	2,267	0.45^{v}
AWD30													
	IR78386H, hybrid rice	10,351	3.48^{a}	2,974	0.34^{a}	13,323	3.53^{a}	3,774	0.27^{a}	10,127	4.37^{b}	2,317	0.48^{a}
	PSB Rc80, inbred rice	11,976	4.48^{a}	2,673	0.37^{a}	11,594	3.77^{a}	3,075	0.33^{a}	9,113	3.98^{c}	2,290	0.39^{a}
	Mean	11,163	3.98^{w}	2,824	0.36^{w}	12,459	3.65^{w}	3,425	0.30^{v}	9,620	4.18^{x}	2,304	0.44^{v}

[a, b] means of rice genotypes for each irrigation method and soil texture with the same letter are not significant difference at the 0.05 probability level using LSD for comparison

[v, w, x] means of irrigation method for each soil texture with the same letter are not significantly different at the 0.05 probability level using LSD for comparison

Table 4b. Irrigation water use, grain yield, water use per kg grain in 3 irrigation methods for the hybrid and inbred genotypes in clay loam and clay soils

		Clay loam				Clay			
Irrigation Method	**Rice Genotype**	Water use for irrigation water only or WUi (m^3 ha^{-1})	Grain yield (t ha^{-1})	Water used (liter)/ 1 kg unmilled rice	Water productivity (Wpi) (kg grain m^{-3} water)	Water use for irrigation water only or WUi (m^3 ha^{-1})	Grain yield (t ha^{-1})	Water used (liter)/ 1 kg unmilled rice	Water productivity (Wpi) (kg grain m^{-3} water)
CF	IR78386H, hybrid rice	5,701	7.75^{a}	736	1.36^{a}	7,252	7.56^{a}	959	1.04^{a}
	PSB Rc80, inbred rice	4,625	6.25^{b}	740	1.35^{a}	6,798	6.98^{a}	974	1.03^{a}
	Mean	5,163	7.00^{v}	738	1.36^{w}	7,025	7.27^{v}	967	1.04^{w}
AWD20	IR78386H, hybrid rice	4,951	7.58^{a}	653	1.53^{a}	4,497	6.86^{a}	656	1.53^{a}
	PSB Rc80, inbred rice	4,561	7.42^{a}	615	1.63^{a}	4,845	6.50^{a}	745	1.34^{b}
	Mean	4,756	7.50^{v}	634	1.58^{v}	4,671	6.68^{v}	701	1.44^{v}

AWD30	IR78386H, hybrid rice	4,488	7.41[a]	606	1.65[a]	4,616	7.69[a]	600	1.67[a]
	PSB Rc80, inbred rice	4,176	6.51[a]	641	1.56[a]	4,406	6.96[a]	633	1.58[a]
	Mean	4,332	6.96[v]	624	1.61[v]	4,511	7.33[v]	617	1.63[v]

[a, b] means of rice genotypes for each irrigation method and soil texture with the same letter are not significant difference at the 0.05 probability level using LSD for comparison
[v, w] means of irrigation method for each soil texture with the same letter are not significantly different at the 0.05 probability level using LSD for comparison

In general, irrigation water is dependent on soil and crop factor. The soil factors include soil texture and soil structure, while the crop factors include rice genotype and crop duration. Sandy loam, silt loam, and loam soil textures contained more sand and bigger pores which caused higher percolation and hydraulic conductivity (percolation is the vertical movement of water beyond the root zone to the ground water table while the soil hydraulic conductivity is the water flow rate vertically from soil surface to the ground water table). This led to higher quantity of irrigation water used than the clay and clay loam soils which contained less sand and smaller pores. Clay and clay loam soils also had the lower hydraulic conductivity; thus, soil textures are attributed to the lower amount of irrigation water use. Castillo *et al.* (2006) reported that the higher the clay content of the soil, the greater the soil fertility and water availability because light-textured soils are characterized by higher water and nutrient losses through percolation. Belder *et al*. (2007) stated that the average percolation rate of the clay and silty clay soils varied between 1.6 and 15.1 mm d^{-1} and the value of saturated hydraulic conductivity of the plow pan varied between 0.4 and 50 mm d^{-1}; it was also in the range of values presented by Wopereis *et al.* (1996b). High percolation rates are matched by higher saturated hydraulic conductivity. At the field level, percolation flows are real water losses for individual farmers. If water is scarce or costly, such as in pump-irrigation schemes, any unproductive water flowing out of a farmers' fields should be minimized (Belder *et al.*, 2007). There was about 29% lesser WUi under AWD20 in loam soil but grain yield decreased by 26% (1.85 t ha^{-1}). This large decrease in yield was not offset by the benefits of water saved. The merit of AWD20, however, was evident in sandy loam soil where there was 44% water saved to produce 1 kg unmilled rice (Table 5). This was due to 38.4% decrease in WUi while grain yields slightly increased at 7.3%.

Indeed, there was an enormous reduction in irrigation water usage between the CF and AWDs in sandy loam, silt loam, and loam soils. The WUi under AWD20 was reduced by about 38% (9,290 m^3 ha^{-1}) in sandy loam soil, 13.1% (2,719 m^3 ha^{-1}) in silt loam soil, and 29.1% (4,844 m^3 ha^{-1}) in loam soil while WUi under AWD30 was reduced by about 53.4% (12,811 m^3 ha^{-1}) in sandy loam soil, 40% (8,312 m^3 ha^{-1}) in silt loam soil and 42.3% (7,048 m^3 ha-

[1]) in loam soil. But the yield decrease was also huge under AWD30 by 38%, 50.5% and 41% in sandy loam, silt loam and loam soils, respectively.

Water productivity of 2 rice genotypes under continuous flooding and AWDs method of irrigation and as influenced by soil textures

Under continuous flooding method of irrigation (CF), the water productivity (WPi) of hybrid rice genotype (IR78386H) ranged from 1.36, 1.04, 0.0.39, 0.30, and 0.40 kg grain m^{-3} water, while for the inbred (PSB Rc80) ranged from 1.35, 1.03, 0.46, 0.24, and 0.32 kg grain m^{-3} water in clay loam, clay, loam, sandy loam, silt loam soils, respectively (Tables 4a and 4b). In the 2-heavy textured soils (clay loam and clay), the IR78386H in CF plots required 848 L on an average of irrigation water used to produce 1 kg of unmilled rice while it was about 2,817 L in the 3 light-textured soils (sandy loam, silt loam, and loam). The IR78386H required lesser irrigation water used in the 2 heavy-textured soils (clay and clay loam) to produce 1 kg of unmilled rice; by about 70% of irrigation water used in the 3 light-textured soils (sandy loam, silt loam, and loam soils). The PSB Rc80 used 857 L on an average of irrigation water used to produce 1 kg of unmilled rice in the 2 heavy-textured soils (clay and clay loam) in CF plots, while it required an average of 3,161 L in the 3 light-textured soils (sandy loam, silt loam, and loam). This translates to about 73% less irrigation water to produce 1 kg of unmilled rice when grown in clay and clay loam soils as compared to sandy loam, silt loam, and loam soils.

The water productivities of 2 genotypes under CF in clay loam and clay soils were significantly higher than those obtained in loam, sandy loam, and silt loam soils. Clay and clay loam used less irrigation water which were about 5,163 m^3 ha^{-1} and 7,025 m^3 ha^{-1}, respectively; while the other three soil types had huge irrigation water usage (sandy loam with 23,974 m^3 ha^{-1}, silt loam with 20,771, m^3 ha^{-1}, and loam with 16,668 m^3 ha^{-1}).

Kato *et al.* (2009) reported earlier that water productivity for irrigation water plus rainwater (WPi+r) under alternate wetting and drying irrigation (AWD) was 0.8–1.0 kg grain m^{-3} water in clay loam soil. These water productivities were slightly higher than those of previous studies on aerobic rice (Bouman *et al.*, 2007; Kato *et al.*, 2006), and substantially higher than the common values of 0.2–0.5 kg grain m^{-3} water for flooded rice (Kamoshita *et al.*, 2007; Tuong *et al.*, 2005). The water productivity (WPi) obtained under AWD20 in clay loam soil in this study was high at 1.58 kg grain m^{-3} water.

The water productivities (WPi) under AWD20 (0.48 kg grain m^{-3} water in sandy loam soil and 0.45 kg grain m^{-3} water in loam soil) were higher than CF (0.27 in sandy loam soil and 0.43 kg grain m^{-3} water in loam soil); and for silt loam, both had the same amount at 0.36 kg grain m^{-3} water. Under AWD30, irrigation water use in sandy loam, silt loam, and loam soils was reduced by about 40% to 53 % but grain yield decreased by about 38–50% (or 2.44–3.73 t ha^{-1}). Because of this significant decrease in grain yield, water productivities were only 0.36, 0.44, and 0.30 kg grain m^{-3} irrigation water for sandy loam, loam, and silt loam soils, respectively. Due to higher grain yield and less irrigation water use as pointed out earlier, water productivities were highest for clay loam soil (1.61 kg grain m^{-3} water) and clay soil (1.63 kg grain m^{-3} water).

Adapted rice genotype could vary with soil texture under AWD20. PSB Rc80 under AWD20 had no significant reduction in yield in sandy loam and silt loam soils, except in loam soil. Peng *et al.* (2006) earlier found that PSB Rc80 was adapted to aerobic condition and flash irrigation of about 5 cm water when the soil moisture tension at 15 cm depth reached 30 kPa. Under AWD20, grain yields in sandy loam (6.89 t ha^{-1}) slightly increased by 7.3% (or 0.47 t ha^{-1}) and there was 38.4% decrease in water use. This increased WPi by about 78%. In silt loam soil, there was 13.1% decrease on irrigation water under AWD20 but grain yield (6.45 t ha^{-1}) decreased by 12.6% (0.93 t ha^{-1}). The WPi was only 0.36 kg grain m^{-3} irrigation water.

AWD20 is a contemporary irrigation technique that can serve as water saving method, particularly in sandy loam soil, as shown in this study. It can replace the higher use of irrigation water in the conventional irrigation method or continuous flooding irrigation (CF), particularly when using an inbred rice genotype like PSB Rc80. Cabangon *et al.* (2001) and Belder *et al*. (2002) previously reported that savings in water use for AWD range 13–30%, with no significant reduction in yield as shown by trials conducted in China and the Philippines. Total rice production can be increased by using water saved in one location to irrigate new lands in another. Field-level water productivity and yield can be increased further by improving total factor productivity and by raising the yield potential of rice genotypes.

Table 5. Percent water saved in AWDs irrigation methods for the hybrid and inbred genotypes compared with the continuous flooding method (CF)

Irrigation Method	**Rice Genotype**	**Sandy loam**	**Silt loam**	**Loam**	**Clay loam**	**Clay**
		% water saved (considering water used to produce 1 kg unmilled rice)				
AWD20	IR78386H, hybrid rice	45	-17	3	11	32
	PSB Rc80, inbred rice	42	16	4	17	24
	Mean	44	-0.5	3.5	14	28
AWD30	IR78386H, hybrid rice	12	-49	9	18	37
	PSB Rc80, inbred rice	35	3	-6	13	35

Mean	24	-23	1.5	16	36

Summary and conclusion

This study was done to quantify water use, grain yield, and water productivity of rice genotypes under conventional continuous flooding irrigation method (CF), alternate wetting and drying irrigation method when the perched water table at 20 cm below the soil surface (AWD20), and alternate wetting and drying irrigation method when the soil moisture tension at 15 cm below soil surface reached 30 kPa (AWD30) in 5 soil textures. Five field experiments were established in two sites (Barangay Pance in Ramos and Barangay Dapdap in Paniqui) in the province of Tarlac, Philippines during the dry season (DS) from November of 2007 to March of 2008. In Barangay Dapdap, two field experiments were laid-out representing sandy loam soil and silt loam soil textures. In Barangay Pance, three field experiments were established representing loam soil, clay loam and clay soil textures. The field experiments were laid out in randomized complete block design with treatments in split-plot arrangements, replicated four times. The three irrigation methods (CF, AWD20 and AWD30) occupied the main plots while the two rice genotypes (PSBRc80 and IR78386H) occupied the subplots.

CF required the highest quantity of irrigation water (WUi) at 23,974 m^3 ha^{-1} (yield at 6.42 t ha^{-1}) in sandy loam soil, followed by 20,771 m^3 ha^{-1} in silt loam soil (yield at 7.38 t ha^{-1}), and 16,669 m^3 ha^{-1} in loam soil (yield at 7.09 t ha^{-1}) . The lowest quantity of WUi was used in clay and clay loam soils at 7,025 m^3 ha^{-1} (yield at 7.27 t ha^{-1}) and at 5,163 m^3 ha^{-1} (yield at 7 t ha^{-1}), respectively.

The water productivities (WPi) of hybrid rice genotype (IR78386H) under CF were 1.36, 1.04, 0.30, 0.40, and 0.39 kg grain m^{-3} water, while for the inbred (PSB Rc80) were 1.35, 1.03, 0.24, 0.32, and 0.46 kg grain m^{-3} water in clay loam, clay, loam, sandy loam, silt loam soils, respectively.

Irrigation water use was significantly lesser in the clay (5,163 m^3 ha^{-1}) to clay loam soil (7,025 m^3 ha^{-1}), hence the highest water productivity because clay and clay loam soils retained water longer due to the reduced loss of water through percolation; the field experimental sites representing clay to clay loam soils had shallower groundwater table depth at 10 to 45 cm and 15 to 42 cm, compared to 60 to 145 cm, 53 to 95 cm, 55 to 85 cm for the sandy loam, silt loam, loam, respectively. The groundwater remained within the root zone for the entire rice growing period in clay and clay loam soils which explain why rice plants did not suffer any water deficit under the designed AWD30 irrigation method.

Growth duration could also explain their difference in water use between inbred and hybrid genotypes. The inbred had 10 days longer growth duration than the hybrid in sandy loam soil, leading to about 15% higher WUi for the inbred. The longer growth duration contributed to the higher amount of irrigation water loss through the percolation and seepage in the light-textured soils (sandy loam, silt loam, and loam soils).

The water productivities (WPi) under AWD20 were higher than CF in sandy loam and loam soils. Under AWD30, irrigation water use in sandy loam, silt loam, and loam soils was reduced by about 40–53% but grain yields of 2 rice genotypes decreased by about 38–50% (or 2.44–3.73 t ha^{-1}). Because of this significant decrease in grain yield, water productivities were only 0.36, 0.30, and 0.44 kg grain m^{-3} irrigation water for sandy loam, silt loam, and loam soils, respectively.

AWD20 is a contemporary irrigation technique that can serve as a water saving method, particularly in sandy loam soil. It can replace the higher use of irrigation water in the conventional irrigation method or continuous flooding irrigation (CF), particularly when using an adapted inbred rice genotype like PSB Rc80.

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