

GRAIN YIELD AND WATER PRODUCTIVITY OF IRRIGATED LOWLAND RICE (*ORYZA SATIVA* L.): THE EFFECT OF ALTERNATE WETTING AND DRYING TECHNOLOGY AND CROP ESTABLISHMENT METHODS

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ABSTRACT

The general objective of the study was to evaluate the effects of crop establishment methods and different water regimes on grain yield and yield components, water input, and water productivity of irrigated lowland rice (PSB Rc80) using field experiment and modeling approaches. The experiment was set up in split plot design. Four water regimes and three crop establishment were evaluated. The field experiment was conducted during the 2011 dry season at WRMC Research Station, CLSU, Science City of Muñoz, Nueva Ecija. The ORYZA2000 model was used to support the analysis of the field experiment. The grain yield under PTR treatment gave the highest mean. For the water regime treatments, CF gave the highest yield and AWD30 gave the lowest yield. The amount of water input showed that DSR had the highest amount, while PTR had the lowest water input. Water savings that ranged from 30.69% to 60.62% were recorded from the use of AWD technology. For the water productivity, PTR treatment gave a mean of 0.23 kg/m³ which was comparable with WSR while DSR had the lowest water productivity. Grain yield, water input, and water productivity were simulated with the support of ORYZA2000 model. The model generally reproduced the experimental values adequately.

Keywords: AWD technology, crop establishment methods, grain yield, water productivity, ORYZA2000 model

INTRODUCTION

Water is becoming a scarce resource in most parts of the world, including Asia. The causes of water scarcity are diverse and location specific.

In the Philippines, the alternate wetting and drying (AWD) technology, has been promoted since 2001 through the Technology Transfer for Water Savings Project of the International Rice Research Institute (IRRI). In AWD, the traditional flooded condition in the rice field is shifted into intermittent non-flooded condition of varying periods before irrigation is again applied.

With increasing water scarcity, the future of rice production will depend on developing and adopting strategies and practices that will lead to efficient water use in the field. Several water saving technologies, from land preparation to crop growth duration, were developed to address the problem of water scarcity in rice irrigated environment. Water saving technologies are aimed to reduce unproductive losses of water, such as seepage and percolation in

the field; hence, increasing the productivity of total water inputs from rainfall and irrigation.

AWD technology saves water compared to continuously flooded condition. While most studies on water saving techniques quantify the reductions in water input, very little research has been done to quantify the effect of AWD on the different crop establishment in the rice fields.

Hence, this study aimed to evaluate the effects of different crop establishment methods and water regimes on the grain yield and water productivity of irrigated lowland rice using field experiment and modeling approaches. Specifically, the objectives of this study were: (1) to determine grain yield and yield components of irrigated lowland rice grown under different crop establishment methods and water regimes, defined by AWD conditions; (2) to evaluate the water input and water productivity resulting from the use of different crop establishment methods and water regimes; and, (3) to simulate the effect of crop establishment methods and water regimes on

grain yield, water input, and water productivity of irrigated lowland rice using ORYZA2000 model.

MATERIALS AND METHODS

Conceptual Framework

Figure 1 shows the conceptual framework of the study. Water scarcity is one of the major concerns in agriculture nowadays, thus water saving technologies should be adopted to lessen water use in the field. Being able to simulate the resulting grain yield, water input, and water productivity as affected by crop establishment methods and water regime treatments without necessarily doing the field work presents another concern.

To address the identified issues and concerns, interventions were introduced, such as AWD technology, different crop establishment methods, and application of ORYZA-2000 model.

The output of the study included water savings, improved water productivity as affected by crop establishment methods and water regime treatments; establishment of recommended crop establishment methods and water regime treatments that would give high yield, water savings, and water productivity; and evaluation of ORYZA2000 model in simulating the grain yield, water input, and water productivity.

Land Preparation

The field was rotavated using a 4-wheel tractor with trailed disc harrow. Bunds and canals were constructed and plastic linings along bunds were installed to a depth of 40 cm.

For the PTR and WSR plots, the land was then soaked, and the field was plowed and harrowed at one week interval using a hand tractor. All crop residues were removed in the field during land preparation. The final harrowing and leveling were done one day before application of these two crop establishment methods. For the DSR treatment, dryland preparation was imposed. The soil was pulverized and plots were leveled.

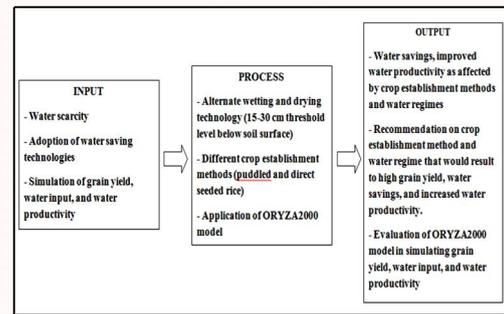


Fig.1. Conceptual framework of the study

Seed Management

In the DSR treatment, pre-germinated seeds were prepared based on a seeding density of 40 kg/ha. Crop establishment was done by manual dry seeding in rows using dry seeds. Row spacing was 25 cm. After seeding, flush irrigation of about 2 cm was applied to promote germination, and water depth was gradually increased up to the time when AWD soil water treatment was imposed.

In the WSR treatment, dry seeds were prepared based on the seeding density of 40 kg/ha. Soaking of seeds in clean water was carried out for 24 hours right after flush irrigation was done with the DSR treatments for synchronous germination. Incubation of seeds was then followed for 24 hours. Crop establishment was done manually or by hand using pre-germinated seed which was placed on top of the wet soil. Seeds were sown 2 days after flush irrigation was initiated with DSR plots. Row spacing was about 25 cm. Water depths were gradually increased up to the time this AWD treatment was imposed.

Under the PTR treatment, dry seeds were prepared based on 25 g/m² seeding density in the seedbed. The seeds were soaked in clean water for 24 hours right after flush irrigating the DSR experimental plots, for synchronous germination. Seeds were incubated for 24 hours. Seedbed was prepared in a separate field and pre-germinated seeds were sown at the seedbed 2 days after flush irrigation with the DSR treatment. Seedlings were transplanted at 20 days after sowing. Using a planting wire with distance markers as guide, seedlings were manually planted at one seedling per hill at 20 x 20 cm plant spacing.

Water Management

The soil was kept saturated for the first 2 weeks after transplanting for the PTR treatments, while DSR and WSR plots were kept saturated up to 35 days after emergence (DAE), to promote better seedling establishment and for weed control. Thereafter, water depth was increased to 5 cm, and AWD and CF water treatments were imposed accordingly.

Timing of irrigation in the AWD plots was based on the water depth in the field water tube (observation well) installed in each plot. When there was no visible water in the tube, irrigation was applied at 5 cm water depth above the soil.

The Use of ORYZA2000 Model

Model Data Inputs.

The ORYZA2000 model requires three data files to use: experimental data file, crop data file, and PADDY file for AWD treatments.

Model Simulation.

The ORYZA2000 model was used to simulate the grain yield and water input, which could provide the data for water productivity determination at the different crop establishment and water regime treatments. Simulated and measured grain yield, water input, and water productivity were compared. For the same variable, a coefficient of determination (R^2) of the linear regression between observed and simulated values was computed.

RESULTS AND DISCUSSION

Table 1 gives the soil properties at the experimental area. The soil type in the area is silty clay loam, based on USDA classification. The average percentage of clay, silt, and sand were comparable for the upper two soil layers (0-10 and 10-20 cm depth) and the lower two soil layers (20-30 and 30-40 cm depth).

Table 1. Soil properties at WRMC Research Station

SOIL PROPERTY	SOIL DEPTH (cm)			
	0-10	10 - 20	20 - 30	30 - 40
clay (%)	34	33	32	33
silt (%)	48	49	55	56
sandy (%)	19	18	13	11
Texture	silty clay loam			
OM (%)	1.98	1.74	1.81	1.54
pH	7.2	6.4	6.8	6.2

Grain Yield

Table 2 presents the mean grain yields of PSB Rc80 at 14% moisture content, using different crop establishment methods and water regimes. Results showed that PTR gave the highest mean yield of 5,714 kg/ha. WSR followed with a mean of 5,237 kg/ha, while DSR had the lowest mean of 3,439 kg/ha. For the water regimes, CF gave the highest mean yield of 5,953.99 kg/ha, followed by AWD15, AWD25, and AWD30 with mean values of 4,829; 4,451; and 3,953 kg/ha, respectively.

Table 2. Mean grain yield of PSB Rc80 at 14% moisture content under different crop establishment methods and water regimes, kg/ha

TREATMENT	CF	AWD 15	AWD 25	AWD 30	MEAN
PTR	7200	6486	4744	4976	5714 ^a
WSR	6910	5155	4927	4055	5237 ^b
DSR	4720	3500	3332	2545	3439 ^c
Mean	5954 ⁱ	4829 ^j	4451 ^k	3953 ^k	

Means not sharing letter in common within column (a,b,c) and within row (i,j,k) differ significantly at 5% level by DMRT

Analysis of variance revealed significant differences by crop establishment methods and water regimes. No significant interaction between crop establishment method and water regime was found in the analysis.

Mean grain yield at CF was significantly higher than AWD treatments. AWD15 treatment had significantly higher yield than AWD 25 and AWD30. When compared with CF, the AWD treatments had yield reduction of 18.90%, 25.25%, and 33.61% for AWD15, AWD25, and AWD30, respectively. These results are in conformity with the rice productivity values obtained by Sahrawat, (2004) under AWD practices and flooded conditions; that is, yield under alternate water management (non-submerged) practices is lower than under flooded conditions.

Number of Tillers per Square Meter

Table 3 presents the average numbers of tillers/m² at physiological maturity of PSB Rc80 as affected by different crop establishment and water regime treatments. Among the crop establishment treatments, DSR gave the highest number of tillers of 666, followed by WSR and PTR, giving mean values of 578 and 477, respectively. For the

water regimes, AWD25 gave the highest number of tillers at 647, followed by AWD30, AWD15, and CF, with mean values of 579, 564, and 505, respectively.

Table 3. Mean number of tillers/m² at physiological maturity stage of PSB Rc80 under different crop establishment methods and water regimes

TREATMENTS	CF	AWD 15	AWD 25	AWD 30	MEAN
PTR	411	444	568	488	477 ^a
WSR	516	509	704	581	578 ^b
DSR	588	740	668	669	666 ^c
Mean	505 ^k	564 ^k	647 ⁱ	579 ^j	

Means not sharing letter in common within column (a,b,c) and within row (i,j,k,) differ significantly at 5% level by DMRT.

Analysis of variance showed that the number of tillers/m² at physiological maturity stage was significantly affected by the crop establishment method and the water regime. However, the number of tillers/m² was not significantly affected by the interaction of the two factors. These findings are in agreement with similar studies of Bhushan, et al. (2007). Their experiments with DSR resulted to a greater number of tillers compared to transplanted rice.

Number of Panicles per Square Meter

The mean numbers of panicles/m² at maturity of PSB Rc80 as affected by different crop establishment methods and water regimes are shown in Table 4. Results revealed that among the crop establishment methods, WSR treatment gave the greatest number of panicles with a mean of 480 while DSR and PTR treatments gave mean values of 474 and 374, respectively. For the water regimes, AWD25 recorded the highest mean value of 488 while AWD15, CF, and AWD30 gave mean values of 445, 420, and 418, respectively.

Analysis of variance revealed significant differences by crop establishment methods and water regimes. No significant interaction between these two factors was found on the number of panicles/m² at maturity. Generally, as the crop suffered drought stress, the number of panicles increased. However, not all panicles were productive or had filled grains owing to the drought stress suffered by the crop.

Table 4. Mean number of panicles/m² of PSB Rc80 under different crop

establishment methods and water regimes

TREATMENTS	CF	AWD1 5	AWD2 5	AWD3 0	MEAN
PTR	371	364	401	359	374 ^b
WSR	428	473	596	426	480 ^a
DSR	461	498	468	469	474 ^a
Mean	420 ^j	445 ^{ij}	488 ⁱ	418 ^j	

Means not sharing letter in common within column (a,b,c) and within row (i,j,k,) differ significantly at 5% level by DMRT.

Number of Grains per Panicle

Table 5 shows the mean numbers of grains per panicle of PSB Rc80 at different crop establishment methods and water regimes. PTR treatment gave the highest number of grains with a mean of 116, followed by WSR and DSR with mean values of 98 and 77, respectively. For water regimes, CF gave the highest mean of 109 followed by AWD15, AWD30, and AWD25 with mean values of 102, 89, and 87, respectively.

Table 5. Mean number of grains per panicle of PSB Rc80 under different crop establishment methods and water regimes

TREATMENTS	CF	AWD 15	AWD 25	AWD 30	MEAN
PTR	131	123	104	104	116 ^a
WSR	105	110	85	90	98 ^b
DSR	91	73	71	73	77 ^c
Mean	109 ⁱ	102 ⁱ	87 ^j	89 ^j	

Means not sharing letter in common within column (a,b,c) and within row (i,j,k,) differ significantly at 5% level by DMRT.

Analysis of variance revealed that there were significant differences by crop establishment methods and water regimes. No significant interaction between these two factors was found in the data analysis.

The results suggest that as rice suffers drought stress, the number of grains per panicle decreases. Also, there were more grains in the panicle for transplanted rice. This observation is in agreement with the results of the experiment of Bhushan, et al. (2007).

Percentage of Filled Grains

Table 6 shows the mean numbers of filled grains of PSB Rc80 at different crop establishment methods and water regimes relative to the total number of harvested grains. PTR treatment gave the highest percentage of filled grains with a mean of 83% followed by WSR with a mean of 79%. DSR treatment gave the lowest percentage of filled grains with a mean of 77%. For the water regimes, AWD25 gave the highest percentage of filled grains followed by AWD30, CF, and AWD15 with mean values of 83, 79%, 78.9%, and 78%, respectively.

Analysis of variance on percentage of filled grains showed that crop establishment methods and water regimes did not give significant differences on the percentage of filled grains.

However, this yield component was significantly affected by the interaction between crop establishment method and water regime.

Table 6. Mean percentage of PSB Rc80 filled grain under different crop establishment methods and water regimes

TREATMENT S	CF	AWD15	AWD25	AWD30	MEAN
PTR	75	84 ^{ym}	85 ^{ym}	86 ^{ym}	83
WSR	81 ^{xn}	69 ^{yn}	84 ^{xn}	81 ^{xn}	79
DSR	80	80 ^{xo}	79 ^{xn}	70 ^{yo}	77
Mean	78.9	78	83	79	

Interaction means in a row (x,y,z) and in a column (m,n,o), differ significantly at 5% level by DMRT.

The reports made by Samoy (2010) and Antolin (2011) showed the same results; that is, the percentage of filled grains was not significantly affected by water regime treatments.

Water Input and Water Productivity

Water Input.

Table 7 shows the total amount of water applied (irrigation + rainfall) for the whole season.

Table 7. Mean values on depth of water applied under different crop establishment methods and water regimes of PSB Rc80, m

TREATMENTS	CF	AWD	AWD	AWD	MEAN

		15	25	30	
PTR	4.1 ^{wm}	3.1 ^{xm}	1.9 ^{ym}	1.9 ^{ym}	2.7 ^a
WSR	4.9 ^{wn}	3.1 ^{xm}	1.8 ^{yn}	1.8 ^{ym}	2.9 ^a
DSR	5.7 ^{wo}	4.0 ^{xn}	2.5 ^{yo}	2.0 ^{zn}	3.6 ^b
MEAN	4.9 ⁱ	3.4 ^j	2.1 ^k	1.9 ^l	

Means not sharing letter in common within row (a,b,c) and column (i,j,k,l), including among interaction means in a row (w,x,y,z) and in a column (m,n,o), differ significantly at 5% level by DMRT.

The larger amount of water input by DSR treatment can be explained by the field plots having been prepared in dryland where high percolation rate occurred in comparison to puddled soil with long soil water retention. According to Rezaei, et al. (2012), the percolation rate of puddled soil is lower in comparison to dryland preparation due to loosening and softening of the puddled layer. Soil puddling destroys soil structure which reduces percolation rate and loss of water.

Water Productivity.

The mean water productivity values by crop establishment methods and water regimes are shown in Table 8. PTR treatment gave the highest mean value of 0.23 kg/m³ for the ratio of the grain yield in kg/ha and the volume of total water input in m³/ha. WSR and DSR treatments had means of 0.20 kg/m³ and 0.11 kg/m³, respectively. For the water regimes, AWD25 treatment gave the highest mean of 0.22 kg/m³. This was followed by treatments AWD 30, AWD15 and CF, with means of 0.20, 0.16, and 0.13 kg/m³, respectively.

Analysis of variance on total water productivity showed that crop establishment method and water regimes had significant effects on water productivity. However, the interaction of crop establishment and AWD treatments gave no significant differences.

Results of this study confirmed the earlier works on AWD technology by Sahrawat (2004) where AWD treatments significantly increased water productivity.

Table 8. Mean water productivity under different crop establishment methods and water regimes, kg/m³

TREATMENT S	CF	AWD15	AWD25	AWD30	MEAN
PTR	0.18	0.21	0.24	0.27	0.23a
WSR	0.14	0.17	0.28	0.22	0.20a
DSR	0.08	0.09	0.13	0.12	0.11b
MEAN	0.13i	0.16i	0.22j	0.20j	

Means not sharing letter in common within column (a,b,c) and within row (i,j,k,) differ significantly at 5% level by DMRT.

Application of ORYZA2000 Model

The computer program to run the ORYZA-2000 model was obtained from IRRI. This was used to do the simulation for grain yield and water input, providing the data base for water productivity determination.

Grain Yield.

ORYZA2000 model gave simulated values of grain yield that ranged from 5,473.40 to 8,716.00 kg/ha in PTR, 5,079.50 to 9,908.50 kg/ha in WSR, and 6,681.90 to 9,767.40 kg/ha in DSR. The simulated values of grain yield were consistently higher than the observed values. Presence of whiteheads and unfilled grains could have accounted for lower observed grain yield.

The coefficient of determination (R^2) of linear regression between observed and simulated values was high, 0.98 under PTR and 0.92 for WSR, suggesting a very good match. The simulation of grain yield for DSR treatment was comparatively less accurate with R^2 of 0.56.

Water Input.

The simulated water input for PTR under CF was 2,528.10 mm, and in AWD water regimes, the simulated values varied from 541.10 to 1,041.10 mm; for WSR under CF, water input was 2,978.00 mm, and under AWD water regimes, from 797.50 to 1,065.50 mm; and for DSR under CF, water input was 3,028.00 mm, and under AWD water regimes, from 815.50 to 1,200.90 mm. The relatively lower simulated amounts of water input may be attributed to the low percolation rate used in the model, whereas in actual field conditions the rate of water percolation was high as evidenced by big cracks of land.

ORYZA2000 model was able to simulate the highest water input for CF treatment and the lowest water input for AWD30. Among crop establishment methods, the model gave DSR the highest water input followed by WSR and PTR, respectively. The coefficient of determination (R^2) under PTR, WSR, and DSR of 0.90, 0.88 and 0.72 reflect moderately adequate fitting of simulated with observed values.

Water Productivity.

The simulated amount of water productivity in PTR under CF condition was 0.34 kg/m³ and under AWD water regimes the value

varied from 0.75 to 1.16 kg/m³; in WSR under CF condition, there was a water productivity of about 0.33 kg/m³, and under AWD water regimes the value varied from 0.63 to 0.69 kg/m³; and, in DSR under CF condition the water productivity was about 0.32 kg/m³ while under AWD water regimes, the values varied from 0.56 to 0.64 kg/m³. A higher value for the simulated water productivity was obtained because the model produced higher yield and lower water input compared to observed values. The coefficient of determination (R^2) between observed and simulated values of water productivity under PTR, WSR, and DSR were 0.92, 0.62, and 0.51, respectively.

CONCLUSION

Based on the objectives of the study, the following conclusions were drawn:

1. The grain yield of PSB Rc80 rice variety was significantly affected by the crop establishment and water regime treatments used in the study. As the threshold water level decreased, grain yield also decreased. PTR gave higher yield than direct seeded rice.
2. Yield components such as the number of tillers/m², the number of panicles/m², and the number of grains per panicle were significantly affected by the use of different crop establishment methods and water regimes. DSR and WSR had higher number of panicles and tillers compared to PTR. A higher number of tillers and panicles did not necessarily give higher yield, because not all tillers and panicles were productive.
3. On water input, direct seeded rice consumed higher amount of water input. For AWD treatments, water savings increased as the threshold level was decreased. The application of water regime treatments translated to water savings of 30.69%, 57.10%, and 60.62% for AWD15, AWD25, and AWD30, respectively, relative to CF treatment.
4. The water productivity of transplanted PSB Rc80 rice variety was higher than the direct seeded rice treatments. As the AWD threshold level decreased, water productivity increased.
5. The application of ORYZA2000 model generally gave adequate simulated values for grain yield, water input, and water productivity of PSB Rc80 rice variety under different crop establishment methods and water regimes. A

value for R^2 closer to 1 was obtained under PTR and WSR, than under DSR.

ACKNOWLEDGEMENT

The authors wish to express their deepest and sincerest gratitude to all persons and institutions that contributed to the success and completion of this piece of work. Sincerest thanks to the Engineering Research and Development for Technology (ERDT) Program of the Department of Science and Technology (DOST) for the financial support.

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