INTEGRATED EFFECT OF IRRIGATION AND NITROGEN ON YIELD, WATER SAVING AND WATER PRODUCTIVITY OF RICE IN NORTH IRAN, USING ORYZA2000 MODEL

IMPACT INTEGRE DE L'IRRIGATION ET DE L'AZOTE SUR LE RENDEMENT, LA CONSERVATION D'EAU ET LA PRODUCTIVITE DE L'EAU SUR LE RIZ EN IRAN DU NORD EN UTILISANT LE MODEL ORYZA2000

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ABSTRACT

For evaluating ORYZA2000 model in Iran, study was carried out in a RCBD between 2005 and 2007, with 3 replications at Rice Research Institute of Iran, Rasht. Irrigation management (continuous submergence, irrigation 5 and 8 day interval) was the main plot and N application (no N application, total N rate of 45, 60 and 75 kg/ha) was the sup-plot. In this study, simulation modeling was used to quantify water productivity, and water balance components of alternate for water–nitrogen interactions in rice. Simulated and measured total aboveground biomass and yield were evaluated by adjusted coefficient of correlation, t-test of means, and absolute and normalized root mean square errors (RMSE). Results show, with normalized root mean square errors ($RMSE_n$) of 5–28%, ORYZA2000 satisfactorily simulated crop biomass and yield that strongly varied among irrigation and nitrogen fertilizer conditions. Yield was simulated with an RMSE of 237–443 kg ha^{-1} and a normalized RMSE of 5–11%. Model ORYZA2000 was sufficiently accurate in the simulation of total biomass and yield under water and nitrogen limit conditions at our test site. This study demonstrates that for estimation of actual plant transpiration and soil evaporation, ORYZA2000 model is useful at field scale. Results show, the significant (28–56%) share of evaporation into evapotranspiration, using the actual yield (measured) and simulated water balance (ORYZA2000). For optimizing N and water apply, one has to define the main constraint to rice production. If it is water shortage, then increasing WP should be the main goal. When water resources are limited, the best irrigation scheme would

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optimize water productivity rather than grain yield. Therefore, for irrigation and nitrogen system managers, the optimum irrigation and nitrogen could be when the highest water productivity is obtained. The calculated average WP_{ET} was significantly lower than the average WP_T: 37%. The average WP_I, WP_{I+R}, WP_{ET}, WP_T and WP_{ETQ} were 1.4, 1.07, 1.07, 1.57 and 0.82 kg m^{-3}. Also results show, irrigation with 8 days interval and 60 kg N/ha, nitrogen level was the optimum irrigation regime and nitrogen level.

Key words: *Rice, Model, Evaluation, Nitrogen, Irrigation.*

RESUME

Cette recherche a été menée dans un plan RCBD lors des années 2005 et 2007, avec 3 répétitions à l'Institut iranien de recherche sur le riz à Rasht pour évaluer le modèle ORYZA2000 en Iran. La gestion d'irrigation (submersion continue, irrigation à l'intervalle de 5 et 8 jours) était le plan principal et l'application de N (aucune application N, taux total N de 45, 60 et 75 kg/ha) était le plan secondaire. Dans cette étude, la modélisation de simulation a été utilisée pour quantifier la productivité de l'eau et les composantes du bilan hydrique pour étudier les interactions eau-azote en riziculture. La biomasse aérienne totale et le rendement simulés et mesurés ont été évalués en utilisant certains indexes statistiques tels que: le coefficient de corrélation ajusté, T-test, l'erreur moyenne quadratique (RMSE) absolue et normalisée.

Les résultats montrent qu'avec RMSE de 5-28%, le model ORYZA2000 a simulé la biomasse et le rendement de manière satisfaisante; ces deux paramètres variaient fortement avec des variations des niveaux d'irrigation et d'azote. Le rendement a été simulé avec un RMSE de 237-443 kg ha^{-1} et un RMSE de 5-11%. Le Modèle ORYZA2000 a été suffisamment précis dans la simulation de la biomasse totale et le rendement dans les conditions de limitation d'eau et d'azote a notre site. Cette étude montre que pour l'évaluation de la transpiration des plantes réelles et l'évaporation du sol, le modèle ORYZA2000 est efficace à l'échelle de la parcelle.

Les résultats montrent la présence de l'évaporation dans l'évapotranspiration (28-56%), en utilisant le rendement actuel (mesuré) et le bilan hydrique simulé (ORYZA2000). Pour optimiser l'application de N et de l'eau, il faut définir les contraintes principales de la production du riz. S'il existe la pénurie d'eau, il faut augmenter la productivité de l'eau (WP). Quand les ressources en eau sont dinsponibles en quantité limitée, le meilleur plan d'irrigation augmentera la productivité de l'eau plutôt que le rendement. Donc, avec la haute productivité de l'eau, les gestionnaires du système d'irrigation et d'azote peuvent atteindre le niveau optimal de l'application d'irrigation et d'azote. Le WP_{ET} moyenne calculée était, de manière significative, inférieure à la moyenne WP_T: 37%. Les moyennes des WP_I, WP_{I+R}, WP_{ET}, WP_T et WP_{ETQ} étaient de 1,4; 1,07; 1,07; 1,57 et 0,82 kg m^{-3}. Selon les résultats obtenues, l'irrigation à l'intervalle de 8 jours et l'application d'azote de 60 kg / ha, était le meilleur régime d'irrigation et le niveau optimal d'application d'azote.

Mots clés: *Riz, modèle, évaluation, azote, irrigation.*

1. INTRODUCTION

ORYZA2000 model is an ecophysiological crop model of the 'School of De Wit' (Bouman et al., 2001). Since the mid-90s, the International Rice Research Institute (IRRI) and Wageningen University and research Center (WUR) have been developing the ORYZA model series to simulate the dynamics of rice growth and development, The first model was ORYZA1 for potential production (Kropff et al., 1994), followed by ORYZA_W for water-limited production (Wopereis et al., 1996), and by ORYZA-N (Drenth et al., 1994) and ORYZA1N (Aggarwal et al., 1997) for nitrogen-limited production. For all production situations, optimal control of diseases, pests, and weeds is assumed. In 2001, a new version in the ORYZA model series was released that improved and integrated all previous versions into one model called ORYZA2000 (Bouman et al., 2001). The ORYZA2000 was evaluated under potential, water-limited, and/or nitrogen (N)-limited conditions in the Philippines (Bouman and Van Laar, 2006), India (Arora., 2006), Indonesia (Boling et al., 2007), Iran (Amiri, 2008) and China (Belder et al., 2007; Jing et al., 2007; Bouman et al., 2007; Feng et al.,2007; Xue et al., 2008).

Agricultural systems are complex, and understanding this complexity requires systematic research, but resources for agricultural research are shrinking. Field experimentation can only be used to investigate a very limited number of variables under a few site-specific conditions. Crop models are useful tools for integrating knowledge of the bio-physical processes governing the plant-soil-atmosphere system, and for extrapolating research results to other locations or sites. Crop simulation models consider the complex interactions between weather, soil properties and management factors (water and N) that influence crop performance. Mechanistic models are very helpful in deciding the best management options for optimizing crop growth and yield. If pests and diseases are controlled, yield of any crop in a given environment mainly depends upon irrigation and fertilizer nitrogen (N) management. Both water and nitrogen are subjected to losses by many pathways if not managed properly. Therefore, there is a considerable interest in technologies that enhance nitrogen use efficiency and productive use of applied irrigation water leading to increased productivity. Field experiments for quantifying optimal crop N and water requirement are time-consuming, requiring many years of trials at multiple locations.

Worldwide, freshwater availability for irrigation is decreasing because of increasing competition from urban and industrial development, degrading irrigation infra-structure, and degrading water quality (Molden, 2007). Because rice receives more irrigation water than other grain crops, water-saving irrigation technologies for rice are seen as a key component in any strategy to deal with water scarcity (Li and Barker, 2004). In order to improve water management and its productivity, we need to reveal the cause effect relationships between hydrological variables such as evaporation, transpiration, percolation or capillary rise, and biophysical variables such as dry matter and grain yields under different ecohydrological conditions. Water productivity, a concept expressing the value or benefit derived from the use of water, includes various aspects of water management and is very relevant for arid and semi-arid regions (Molden and Sakthivadivel, 1999; Molden et al., 2001; Droogers and Bastiaanssen, 2002; Kijne et al., 2003). It can be expressed in terms of grain (or seed) yield per amount of water used in different processes such as transpiration, evapotranspiration and percolation, and provides a proper diagnosis of where and when water could be saved. Measurements of the required hydrological variables under field conditions are difficult, and need sophisticated instrumentation or installation of lysimeter. Moreover, field experiments yielding site-specific information are very expensive, laborious and time consuming to conduct for all ecohydrological conditions, especially if they should be representative for a sequence of years. However, models like ORYZA2000 model in combination with field experiments offer the opportunity to gain detailed insights into the system behaviour in space and time. Water productivity can be defined as total water input through rainfall and irrigation or as evapotranspiration (ET). Tuong and Bouman, (2003) and Zwart and Bastiaanssen (2004) reported values for water productivity in rice based on ET, WP_{ET}, range from 0.4 to 1.6 kg/m^3.

In this paper, we study and compare the water productivity, and water balance components (evaporation, transpiration and percolation) of variable irrigation regimes and nitrogen fertilizer levels. Using measured crop variables; we calibrated and evaluated the crop growth model ORYZA2000, and then used the model to determine in detail the parameters of the water balance of the field experiments for find the optimum irrigation regime and nitrogen level.

2. MATERIALS AND METHODS

The experiments were conducted from 2005 to 2007 at Rice Research Institute of Iran, Guilan province, located in the north of Iran (37°12′ N, 49°38′ E), at the rice cultivation season. The design of the management was split plot in complete randomized blocks and three replicates. The main plots were three irrigation regimes:

I1: continuous submergence (standing water was maintained 30-50 mm throughout crop growth), I2: irrigation 5 day interval and I3: irrigation 8 day interval.

The subplots (15 m^2) consisted of four N-levels: N1: no N application, N2: total N rate of 45 kg/ha, N3: total N rate of 60 kg/ha and N4: total N rate of 75 kg/ha.

Variety used was *Hashemi*, widely cultivated in Guilan province. Seedlings were grown in wet beds for approximately 25-30 days and transplanting was done at 3 plants per hill with a spacing of 20×20 cm. Complete pest control was done in all plots to prevent any interference from weeds, diseases, or insects that would hinder full quantitative assessment of nutrient×water interactions. A mixed commercial fertilizer was applied at the rate of 25 kg P ha^{-1} and 75 kg K ha^{-1}: all of phosphorous, potassium, and half of nitrogen fertilizer (N2, N3 and N4-level) were applied at basal and other 50% nitrogen fertilizer has applied as a top dressing at maximum tillering. All plots were bunded and separated by 0.5-m wide strips of bare soil to avoid lateral movement of water and nutrients among management. For each management, the dates of emergence, panicle initiation, flowering, and physiological maturity were recorded. Grain yield was measured from a central 5 m^2 and is reported at 14% moisture. The dry weights were obtained after oven-drying at 70°C to constant weight, and are reported here as total biomass.

A detailed description of the model is given by Bouman et al. (2001) and just summary of the model has described in this section. ORYZA2000 follows a daily calculation pattern for the rate of dry matter production of the crop organs, and the rate of phenological development. By integrating these rates over the time, dry matter production and development stage were simulated through the growing season. The calculation processes for dry matter production were well documented (Bouman et al., 2001). Total daily rate of canopy CO_2 assimilation was calculated from daily incoming radiation, temperature, and leaf area index (LAI). The daily dry matter accumulation was calculated by subtraction of maintenance and growth respiration requirements from total assimilation amount. The dry matter increment was partitioned among the various plant organs as a function of phenological development stage, which is tracked as a function of mean daily air temperature. Spikelet density at flowering was derived from total dry matter accumulation over the period of panicle initiation to flowering stage.

Several statistical methods were used to compare the simulated and observed results. In this paper used a combination of graphical analyses and statistical measures, graphically compared the simulated and measured final biomass and yield. In this paper evaluated model performances using the absolute root mean square error (RMSE) and root mean square error normalized ($RMSE_n$). RMSE and $RMSE_n$ characteristics are common tools to test the goodness of fit of simulation models (Bouman and Van Laar, 2006):

$$\mathrm{RMSE} = \left(\sum_{I=1}^{n} (P_i - O_i)^2 / n\right)^{0.5} \quad (1)$$

$$\mathrm{RMSE_n} = 100\left(\sum_{I=1}^{n} (P_i - O_i)^2 / n\right)^{0.5} / O_{mean} \quad (2)$$

Where P_i is the simulated value, O_i is the measured value, and n is the number of measurements. Paired *t*-tests and linear regression analysis were also used to assess the goodness-of-fit between the observed and simulated results. If the P-value (P (t)) from the paired t-test was greater than 0.05, it was concluded that no significant differences existed between the measured and simulated values.

Water productivity means quantum of production per unit water used (Molden 1997, Molden et al. 2001). The denominator unit water used or committed is varies significantly with respect to scale (Molden et al. 2001, Kijne et al. 2003). Water productivity can be defined in different ways referring to different types of 'crop production', i.e. dry matter or grain yield, and 'amount of water used', i.e. transpiration, evapotranspiration and irrigation (Molden et al., 2001). We used the following definitions of water productivity (Table 1). WP_T is expressed in crop grain yield Y_g per unit amount of transpiration T, and sets the lower limit of water used by crop. The actual evapotranspiration ET represents the actual amount of water used in crop production, which is no longer available for reuse in the agricultural production system. It must be used as productive as possible, and it is logic to express WP_{ET} in terms of Y_g per unit amount of ET. The inevitable loss of water due to evaporation decreases the water productivity from WP_T to WP_{ET}. Therefore, relative low values of WP_{ET} as compared to WP_T suggest the need to reduce evaporation by agronomic measures such as soil mulching and conservation tillage. Similarly, including percolation Q_{bot} enlarges the denominator in expression of water productivity, and hence decreases it from WP_{ET} to WP_{ETQ}. Whether Q_{bot} should be considered as a loss, it depends on the groundwater quality of the region. The irrigation and rainfall is the total water applied to the field. In this case, the water productivity WP_I and WP_{I+R} expressed in terms of Y_g per unit water available in the field through irrigation I and rainfall R.

3. RESULTS AND DISCUSSION

The model was calibrated using data for 2007 growing season, while the data for 2005 and 2006 growing seasons were used for model validation. The ORYZA2000 model was evaluated in respect of simulation of grain yield and total biomass in variable irrigation regimes and nitrogen fertilizer levels. The indigenous soil N supply rates 0.9 kg ha^{-1} day^{-1} found in our experiments compare well with values of 0.5–0.9 kg reported for tropical rice soils by Ten Berge et al. (1997), and with values up to 1 kg ha^{-1} day^{-1} reported by Dobermann et al. (2003 a, b) for Southeast China.

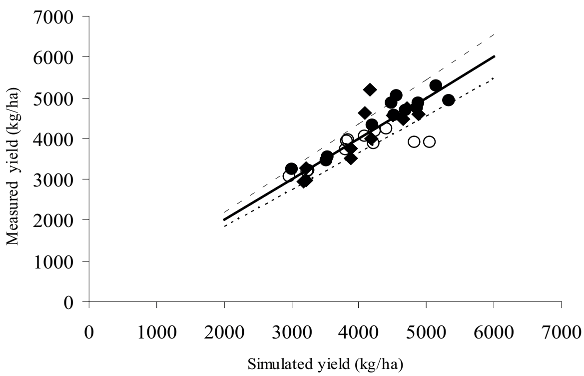
The root mean square error (RMSE) was between 237-443 kg ha^{-1} and normalized RMSE was 5-11 % for measured yields varying between 2956 and 5290 kg ha^{-1}. Harvest-time biomass was slightly over predicted with a RMSE of 530-2300 kg ha^{-1} and normalized RMSE between 9 and 28 % for measured total biomass ranging between 6028 and 11173 kg ha^{-1}. Paired t-test showed no significant differences between the measured and simulated yield and total biomass values (except total biomass for 2005 at $P = 0.05$ confidence level).

Figure 1, compares simulated with measured yield (A) and final biomass (B) for all data of the calibration and validation sets. For reference, the 1:1 line plus and minus the SE of the measured variables was also shown. Nearly 80% biomass and 90% yield data points fell within the plus and minus SE lines of measured biomass. The linear regression between simulated and measured values had a slope α close to 1, an intercept β that was relatively small (compared with the range in the variable values), and an R^2 larger than 0.60 for all variables, indicating a close correlation between the simulations and the measurements.

The capability of ORYZA2000 model to simulate rice production in a water and nitrogen limited environment was tested against data derived from a field experiment (Figure 2). The simulated yields were within one standard deviation of the measured values in all years except irrigation regimes I3 (N3 and N4, 2006) and I2 (N3 and N4, 2005 and 2007).

The water productivity for rice was analyzed through ORYZA2000. We calculated the water productivity values using the simulated water balance components T, ET and Q_{bot} by ORYZA2000 and the actual (measured) grain yield Y_g (Table 3).

A



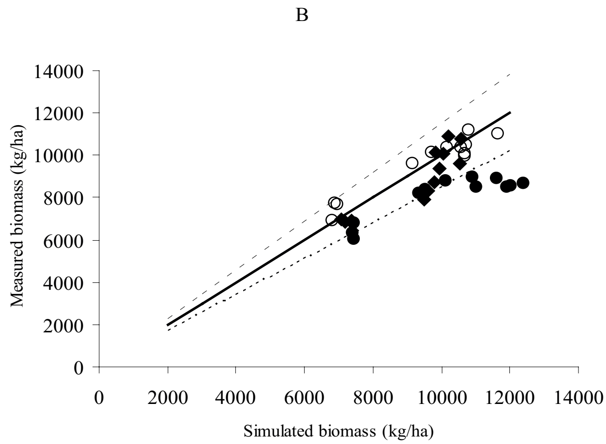


Fig. 1. Simulated versus measured end-of-season yield (A) and biomass (B). Solid lines are the 1:1 relationship; dotted lines are plus and minus standard deviation around the 1:1 line as derived from a data set using in 2005–07.

Table 1. Water productivity WP (kg m^{-3}) expressed as crop production (kg m^{-2}) per unit amount of water used (m^3 m^{-2})

WP	Definition[a]	Unit	Field scale
WP_T	Yg/T	Kg/m^3	T
WP_{ET}	Yg/ET	Kg/m^3	E+T
WP_{ETQ}	Yg/ETQ	Kg/m^3	$E+T+Q_{bot}$

a: Yg is the crop grain (or seed) yield, T is the actual transpiration, E is the actual soil evaporation, and Q_{bot} is the Percolation.

Table 2. Evaluation results of ORYZA2000 simulations of crop parameters, for the calibration and validation conditions

Year	crop variable	N	X_{obs} (SD)	X_{sim} (SD)	α	β	R^2	P(t)	RMSE absolute	$RMSE_n$ (%) normalized
	calibration									
2007	Final biomass (Kg ha^{-1})	12	8833(1486)	9248(1288)	1.01	-556	0.77	0.09	784	8
	Yield (Kg ha^{-1})	12	4062(753)	4046(596)	1.06	-255	0.71	0.77	389	9
	Validation									
2006	Final biomass (Kg ha^{-1})	12	9565(1718)	9632(1394)	1.18	1892	0.93	0.66	503	5
	Yield (Kg ha^{-1})	12	4467(628)	4395(706)	0.91	467	0.88	0.30	237	5
2005	Final biomass (Kg ha^{-1})	12	8051(1040)	10105(1865)	0.48	3119	0.76	0.00	2300	28
	Yield (Kg ha^{-1})	12	3767(397)	3977(628)	0.47	1819	0.60	0.17	443	11

N, number of measured/simulated data pairs; Xobs, mean of measured values in whole population; Xsim, mean of simulated values in whole population; SD, standard deviation of population; α, slope of linear relation between simulated and measured values; β, intercept of linear relation between simulated and measured values; R^2, adjusted linear correlation coefficient between simulated and measured values; RMSE, absolute root mean square error; $RMSE_n$ (%), normalized root mean square error. * means simulated and measured values are the same at 95% confidence level.

Table 3. Water productivity of rice under irrigation and Nitrogen conditions, 2005-07

		Year														
		2005					2006					2006				
Irrigation regime	N-level (kg/ha)	WP_I	WP_{I+R}	WP_{ET}	WP_T	WP_{ETQ}	WP_I	WP_{I+R}	WP_{ET}	WP_T	WP_{ETQ}	WP_I	WP_{I+R}	WP_{ET}	WP_T	WP_{ETQ}
Continuous submergence	0	0.61	0.50	0.59	1.27	0.43	0.71	0.55	0.68	1.32	0.47	0.50	0.45	0.55	1.29	0.39
	45	0.78	0.64	0.73	1.19	0.55	0.91	0.77	0.95	1.45	0.65	0.69	0.64	0.79	1.39	0.54
	60	0.81	0.66	0.74	1.18	0.56	0.98	0.81	0.93	1.57	0.66	0.76	0.66	0.81	1.53	0.58
	75	0.76	0.63	0.71	1.12	0.54	0.95	0.76	1.01	1.48	0.69	0.78	0.65	0.79	1.47	0.56
	0	0.82	0.64	0.77	1.39	0.53	0.93	0.67	0.81	1.40	0.55	0.61	0.61	0.74	1.38	0.48
5-Day interval	45	1.04	0.82	0.89	1.30	0.67	1.30	0.91	1.00	1.47	0.73	0.73	0.71	0.81	1.27	0.56
	60	1.02	0.79	0.81	1.12	0.64	1.22	0.94	1.04	1.55	0.77	0.95	0.90	1.04	1.62	0.71
	75	0.97	0.76	0.79	1.11	0.62	1.23	0.94	1.03	1.53	0.75	1.05	1.02	1.16	1.80	0.80
	0	1.02	0.75	0.85	1.38	0.60	1.23	0.84	0.84	1.30	0.65	0.86	0.78	0.86	1.56	0.60
	45	1.37	1.01	0.98	1.37	0.77	1.45	1.09	1.02	1.46	0.80	1.03	0.91	0.92	1.37	0.68
8-Day interval	60	1.24	0.91	0.91	1.32	0.72	1.63	1.20	1.17	1.68	0.91	1.32	1.11	1.13	1.70	0.83
	75	1.34	0.98	0.98	1.41	0.76	1.54	1.27	1.18	1.67	0.92	1.20	1.06	1.09	1.63	0.81

Both water productivities WP_{I+R} and WP_I showed a maximum value with interval irrigation regimes. The WP_{I+R} increased from as low as 0.5 kg/m^3 at continuous submergence management to 1.54 kg/m^3 at irrigation 8 day interval, because the decrease in irrigation water requirements over that range outweighed the decrease in yield. It is reported by Tuong and Bouman (2003) and Bouman and Tuong (2001) that the water productivity of irrigated rice is ranges from 0.20 to 1.1 kg/m^3.

In 0-N plots, WP_{ET} ranged from 0.55 to 1.01 kg/m^3 while in 75-N plots, in continuous submergence plots, WP_{ET} ranged from 0.71 to 1.18 kg/m^3 while in interval irrigation plots (Table 3), Differences between seasons mainly followed the trends in differences in grain yield. It is reported by Tuong and Bouman (2003) and Bouman and Tuong (2001) that the water productivity of rice, WP_{ET} values under typical low land condition range from 0.4–1.6 kg/m^3. Based on a review of 82 literature sources with results of experiments in the last 25 years, Zwart and Bastiaanssen (2003) established global benchmark values of WP_{ET}, expressed as Yg/ET (kg/m^3), at 1.09 for rice. To improve the WP_{ET} for a crop, the fraction of soil evaporation E in evapotranspiration ET is important. In experiments, N application and interval irrigation increased water productivity (WP_{ET}). To improve the WP_{ET} for a crop, the fraction of soil evaporation E in evapotranspiration ET is important (Table 3). During the rice cultivation, the high evaporative demands and continuously surface water ponding result in high soil evaporation. Improving agronomic practices such interval irrigation can reduce this non-beneficial loss of water through soil evaporation E, and subsequently will improve the WP_{ET}. Reducing water inputs from continuous flooded conditions to soil saturation or alternate wet/dry conditions will slightly decrease the rice yields, but will substantially increase the water productivity (Bouman and Tuong, 2001).

In this study, the average value of WP_{ET} is 0.89 kg/m^3 and 37% lesser than WP_T. The differences in WP_T for different management are due to the differences in the chemical composition, harvest index and evaporative demands during the respective seasons. The harvest index of rice can be manipulated by irrigation and fertilization. With supplemental irrigation, small amounts of irrigation are carefully applied at critical times of the growing season, such as at flowering and grain filling, to maintain a high harvest index (Oweis and Hachum, 2003).

The percolation Q_{bot} further reduces the WP_{ET} to WP_{ETQ} (Table 3). The average WP_{ETQ}, expressed as Yg/ETQ (kg/m^3), was 1.07. Usually in irrigated areas Q contributes to the groundwater recharge, which is recycled through groundwater pumping in good quality groundwater areas. Therefore, the reduction of Q will be beneficial for improving the low WP_{ETQ} values in the poor quality groundwater areas.

For optimizing N and water apply, one has to define the main constraint to rice production. If it is water shortage, then increasing WP should be the main goal. If water is amply available, then optimizing grain yields by improved N management should be the main goal. When water resources are limited, the best irrigation scheme would optimize water productivity rather than grain yield (Bouman and Tuong 2001). Therefore, for irrigation and nitrogen system managers, the optimum irrigation and nitrogen could be when the highest water productivity is obtained. In figure 2, the average of water productivity components during years has been calculated for irrigation regimes and nitrogen fertilizer levels. As it can be seen, change of irrigation method and increase of nitrogen fertilizer improve the water productivity components. Of course, the increase of water productivity can not be seen in the amounts of higher nitrogen fertilizer. A result shows that between performed water-nitrogen scheme, whit respect to the water productivity components, the irrigation 8 day interval regime and nitrogen level of 60 kg N/ha is the optimum irrigation regime and nitrogen fertilizer level. The average of 3 years yield of that water-nitrogen scheme was 4446 kg/ha and also the average WP_I, WP_{I+R}, WP_{ET}, WP_T and WP_{ETQ} of that water-nitrogen scheme were 1.4, 1.07, 107, 1.57 and 0.82 (kg/m^3).

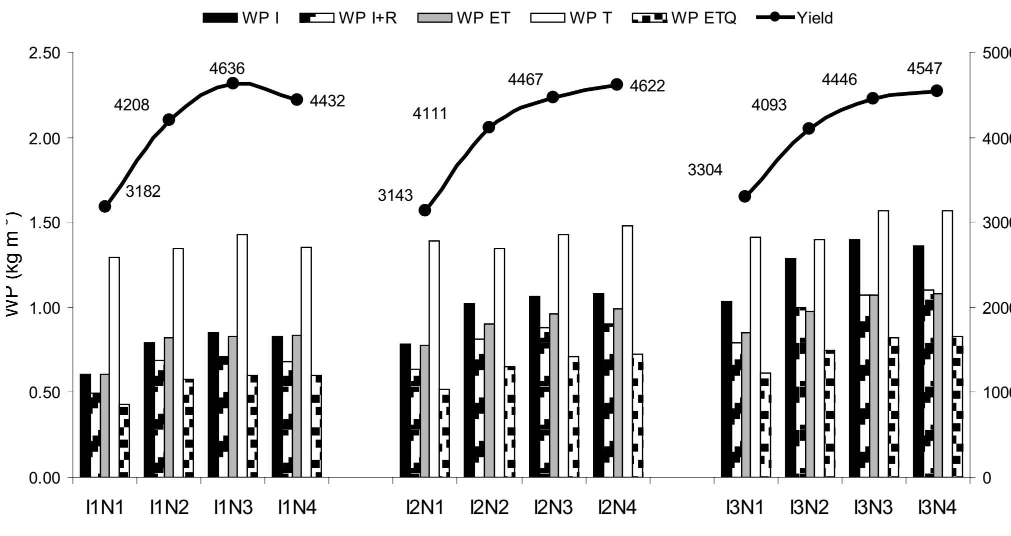


Fig. 2. Water productivity of rice under irrigation and nitrogen conditions.

The eco-physiological model ORYZA2000 in combination with field experiments can be used to quantify hydrological variables such as transpiration, evapotranspiration and percolation, and biophysical variables such as grain yields, which are required for water productivity analysis of rice crop. This study demonstrates that for estimation of actual plant transpiration and soil evaporation, ORYZA2000 model is useful at field scale. Results show, irrigation with 8 day interval and 60 kg N/ha, nitrogen level was the optimum irrigation management and N application.

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