International Journal of Philippine Science and Technology, Vol. 08, No. 2, 2015

SHORT COMMUNICATION

Relationship of agro-morphological traits to water use efficiency of irrigated lowland rice varieties under screenhouse condition

Ace Mugssy L. Agustin*[1,2] and Nina M. Cadiz[3]

[1]Graduate School, University of the Philippines Los Baños,
College, Laguna 4031
[2]Department of Crop Science, College of Agriculture, Central Luzon State
University, Science City of Muñoz, Nueva Ecija 3120
[3]Institute of Biological Sciences, College of Arts and Sciences, University of
the Philippines Los Baños, College, Laguna 4031

Abstract—Rice (*Oryza sativa* L.) is the only cereal food crop that grows in different hydrological conditions. As staple food in the Philippines, it is cultivated in different parts of the country from irrigated to rainfed lowland, upland, cool elevated, flood-prone, and saline ecosystems. Among these ecosystems, irrigated lowland has highest production, however its productivity is threatened by increasing water scarcity. Crop water use efficiency is widely used to evaluate productivity in terms of water use. However, currently, there are limited studies in this area particularly on the relationship of agro-morphological traits to water use efficiency which can be used by breeders to improve rice water use efficiency. Hence, this study aimed to identify the relationship of agro-morphological traits to biomass production, evapotranspiration, and water use efficiency of irrigated lowland rice varieties, and to identify growth phase and variety with highest water use efficiency. Three irrigated lowland rice varieties were grown in the pots with 40cm x 30cm (row x hill) planting distance under screenhouse condition. This was laid-out in split-plot in Randomized Complete Block Design with growth phase as main plot and variety as sub-plot, replicated three times. Based on the result, broad leaf contributed in decreasing evapotranspiration and increasing biomass and water use efficiency. Broad leaves have higher boundary layer and contribute to better covering of soil surface both of which reduce evapotranspiration, and contribute to higher light interception for higher biomass production, hence high water use efficiency. Other traits such as long leaf, high spikelet fertility, heavy grain, and early maturity also contributed to reduction of evapotranspiration and improvement of water use efficiency. Hence, these traits might have the potential to improve water use efficiency of irrigated lowland rice varieties. Among growth phases, reproductive phase had highest water use efficiency due to higher rate of increase in biomass and lower rate of increase in evapotranspiration than ripening phase. NSIC Rc202H with broadest leaves and lowest cumulative evapotranspiration had highest water use efficiency than NSIC Rc222 and PSB Rc18.

Keywords—irrigated lowland rice, agro-morphological traits, biomass, evapotranspiration, water use efficiency, broad leaf

INTRODUCTION

Rice is a diverse plant species which can grow in a wide range of environment, particularly in different hydrological conditions. It is the only major cereal food crop that can grow in flooded condition (Bouman et al., 2007). In the Philippines, it is the staple food which is cultivated in different parts of the country from irrigated to rainfed lowland, upland, cool elevated, flood-prone, and saline ecosystems. Among these ecosystems, irrigated lowland has the highest production (13.82 M t) with 3.24 M ha cultivated area hence, the major contributor to domestic rice production (72%) (Bureau of Agricultural Statistics, 2014). However, aside from challenges in breaking the yield plateau in this ecosystem, there is increasing threat in existing productivity due to negative effects of climate change particularly water scarcity. Amount of rainfall will be reduced in some areas resulting to lower water level of dams (Cruz and Jose, 1999), which is happening nowadays particularly in Angat (Republic of the Philippines Water Situation Report, 2006) and Pantabangan dams (Philippine Atmospheric, Geophysical and Astronomical Services Administration, 2014). Also, competition in water use is increasing among industry, household and agriculture (RP Water Situation Report, 2006). Different studies have been done to reduce the water application and increase the genotypic water use efficiency (WUE) of rice. To reduce water application, there are different technologies and practices, such as: dry soil tillage

***Corresponding Author**
Email Address: mugssy_ace@yahoo.com
Submitted: May 19, 2015
Revised: September 26, 2015
Accepted: October 7, 2015
Published: December 4, 2015

soon after harvesting, no tillage, proper land levelling, direct seeding, construction of field channels and bunds, saturated soil culture, and alternate wetting and drying (AWD) (Tuong and Bhuiyan, 1999 and Bouman et al., 2007). High genotypic WUE on the other hand, can be achieved by reducing crop growth duration (early maturity) and increasing the output (high yield) (Tuong and Bhuiyan, 1999). However, according to Yoshida (1981), the amount of water use is directly related to biomass. As the biomass increases the water use also increases and might not give significant change in the value of WUE. According to Blum (2005), it is a controversial selection parameter for high yield particularly under drought stress. Furthermore, studies on plant traits in relation to water use are extensive only under drought stress condition and very limited under irrigated condition. This study, therefore, aimed to identify the relationship of agro-morphological traits to biomass production, evapotranspiration (ET) and WUE of high yielding irrigated lowland rice varieties and to identify growth phase and variety with highest WUE.

MATERIALS AND METHODS

Time and Place of Study

This screenhouse study was conducted from October 2014 to February 2015 at the Institute of Biological Sciences, University of the Philippines Los Baños (IBS-UPLB), Los Baños, Laguna.

Experimental Design

The experiment was laid-out in split-plot in Randomized Complete Block Design (RCBD) as precaution from observed heterogeneity of light availability. Growth phase was assigned as main plot while variety as sub-plot. This was replicated three times with two plants for each replication.

Plant Materials

Widely-cultivated irrigated lowland rice varieties with different maturity were used to determine if the ET is a function of growth duration or other parameters. NSIC Rc222 (*Tubigan* 18) is the most popular inbred in Central Luzon particularly in Nueva Ecija – province with the highest average yield of rice (National Cooperative Testing), because of its high yield under farmer's field which is almost the same with hybrids. Another popular inbred is PSB Rc18 (*Ala*) which is widely-cultivated across the country because of its acceptable yield (5.1 t ha^{-1}), moderate resistance to pests and diseases, and good eating quality, a late-maturing variety. Hybrid variety was also tested, NSIC Rc202H, commonly known as *Mestizo* 19, a two-line hybrid, early maturing and high-yielding variety (6.7 t ha^{-1}) (Philippine Rice Research Institute, 2014).

Crop Establishment

Twenty one (21) day old seedlings were transplanted in each pot with one hill (2-3 seedlings) per pot (25 cm x 25 cm, H x Dm) with 40 cm x 30 cm (row x hill) planting distance. The pot was filled with clay from rice field up to 20 cm. General fertilizer recommended rate (90-60-30 kg NPK ha^{-1}) was followed with 0.86 g 14-14-14 applied basally, 0.60 g 16-20-0 and 0.12 g 46-0-0 was topdressed in each pot during active tillering and panicle initiation (PI) stages, respectively. Weeds were removed immediately throughout the experiment. Five centimeters depth of water was provided to each pot when surface water was dropped using graduated cylinder to measure the applied amount of water.

Data Gathered

Evapotranspiration (ET)

This was measured by watering the pot using graduated cylinder. Cumulative ET for each growth phase was computed by adding the water applied from transplanting to PI (vegetative), to flowering (reproductive), and to maturity (ripening). Daily ET for vegetative, reproductive and ripening phases were computed using Equations 1, 2, and 3, respectively.

$$\text{Daily ET in vegetative phase} = \frac{\text{Cumulative ET from translating to PI}}{\text{Number of days from transplanting to PI}} \quad \text{Eqn. 1}$$

$$\text{Daily ET in reproductive phase} = \frac{\text{Cumulative ET from PI to flowering}}{\text{35 days}} \quad \text{Eqn. 2}$$

$$\text{Daily ET in ripening phase} = \frac{\text{Cumulative ET from flowering to maturity}}{\text{30 days}} \quad \text{Eqn. 3}$$

Agro-morphological traits

The following agro-morphological traits were gathered: plant height, number of tiller per hill, number of leaf per tiller, number of panicle per hill, leaf length, leaf width, leaf area, stem length, dry weight of above ground biomass (leaf, stem, and panicles), panicle length, number of spikelet per panicle, spikelet fertility, 1000-grain weight, and grain yield. Biomass for vegetative, reproductive and ripening phases were gathered by harvesting the plants during PI, flowering, and maturity, respectively. The leaf area was estimated using conventional method (Yoshida et al., 1976) wherein the second topmost tiller was selected as sample tiller. The length and the widest width of all the green leaves in sample tiller were measured. Leaf area was computed by multiplying length to width then the product was multiplied by correction factor 0.75. The corrected leaf area of each leaf was summed-up to get the total leaf area per tiller then multiplied with the number of tillers to estimate the final leaf area per hill.

Water use efficiency

Water use efficiency of biomass (WUE_B) and grain yield (WUE_G) for each variety were determined. For WUE_B during vegetative, reproductive, and ripening phases were computed using Equations 4, 5, and 6, respectively, while equation 7 was used to compute WUE_G.

$$WUE_B \text{ in vegetative phase} = \frac{\text{Biomass in PI}}{\text{ET from transplanting to PI}} \quad \text{Eqn. 4}$$

$$WUE_B \text{ in reproductive phase} = \frac{\text{Biomass in flowering}}{\text{ET from transplanting to flowering}} \quad \text{Eqn. 5}$$

$$WUE_B \text{ in ripening phase} = \frac{\text{Biomass in maturity}}{\text{ET from transplanting to maturity}} \quad \text{Eqn. 6}$$

$$WUE_G = \frac{\text{Grain yield at 14\% moisture content}}{\text{ET from transplanting to maturity}} \quad \text{Eqn. 7}$$

Statistical analysis

Analysis of variance (ANOVA) appropriate to split-plot RCBD was used. Comparison among means was done using least of significance difference (LSD) at 5% level of significance. Pearson correlation analysis was performed to understand the relationship of agro-morphological traits to biomass, ET, and WUE. These were performed using STAR (Statistical Tool for Agricultural Research) (version 2.0.1) Statistical Software developed by Biometrics and Breeding Informatics Group of Plant Breeding, Genetics and Biotechnology Division (PBGBD) of International Rice Research Institute (IRRI).

RESULTS

Relationship of Agro-morphological Traits to Biomass Production, ET and WUE

In terms of biomass production, above ground biomass and grain yield showed very strong linear relationship with each other (Table 1). Both had strong positive relationship to stem weight and panicle number, while negative strong relationship to leaf:stem weight ratio. Furthermore, biomass had at least strong relationship to stem length, leaf width, leaf weight, and maturity while negative strong relationship to spikelet fertility and flag leaf area. Grain yield, on the other hand, had negative strong relationship to leaf length. Thus, heavy stem weight, more panicles and lower leaf:stem weight ratio might contributed to the productivity of these irrigated lowland rice varieties. Cumulative ET, on the other hand, had very strong positive linear relationship to stem weight, biomass and maturity and strong relationship to grain yield. On the other hand, leaf length, width and area, spikelet fertility, flag leaf area and 1000-grain weight had at least strong negative relationship to cumulative ET. The relationships of these parameters, except for grain yield, to WUE were opposite to that of cumulative ET and these relationships were further supported by daily ET and daily WUE.

Table 1. Correlation coefficients of agro-morphological parameters to evapotranspiration (ET) and water use efficiency (WUE).

	LL	LW	LA	SW	LWt	L:S	MAT	PN	PL	SN	SF	FLA	OGW	HI	BM	GY	ETd	WUEd	Cum ET	WUE cum
SL	0.84**	0.85**	0.69**	0.91**	0.92**	-0.93**	-0.14	-0.61*	0.66	0.71*	-0.10	0.42	0.03	0.48	0.80**	0.11	0.72**	0.71**	-0.14	0.20
LL		0.67**	0.84**	0.81**	0.81**	-0.82**	-0.82**	-0.40	-0.47	-0.43	0.75**	0.88**	0.45	0.14	0.53**	-0.61	0.41*	0.64**	-0.87**	0.86**
LW			0.39*	0.69**	0.70**	-0.81**	-0.76*	-0.46	-0.10	0.02	0.59	0.82	0.49	0.59	**0.87****	-0.12	**0.75****	**0.86****	**-0.76***	**0.88****
LA				0.71**	0.71**	-0.70**	-0.86**	-0.08	-0.65	-0.69*	0.71*	0.60	0.67*	0.27	0.19	-0.52	0.10	0.37	-0.81**	0.71*
SW					0.93**	-0.92**	0.69*	0.59	0.50	0.62	-0.74*	-0.43	-0.48	-0.16	0.74**	0.77*	0.72**	0.61**	0.84**	-0.65
LWt						-0.88**	0.60	-0.04	-0.13	-0.12	-0.24	-0.60	-0.62	-0.85**	0.71**	-0.21	0.68**	0.61**	0.32	-0.43
L:S							0.13	-0.39	-0.37	-0.42	0.20	-0.26	-0.29	-0.66	-0.76**	-0.63	-0.69**	-0.72**	-0.20	-0.01
MAT								0.25	0.50	0.49	-0.83	-0.79	-0.72	-0.58	0.74*	0.40	0.89**	-0.80**	0.89**	-0.88**
PN									-0.22	-0.21	-0.21	-0.44	0.07*	0.06	0.64	0.65	0.61	-0.45	0.49**	-0.34
PL										0.86	-0.46	-0.11	-0.56	0.09	0.43	0.43	0.42	-0.43	0.54	-0.44
SN											-0.65	-0.09	-0.52	0.01	0.50	0.47	0.43	-0.44	0.53	-0.41
SF												0.61	0.46	0.41	-0.62	-0.38	-0.73*	0.82*	-0.79	0.81**
FLA													0.51	0.44	-0.60	-0.35	-0.73*	0.83*	-0.78*	0.85**
OGW														0.61	-0.51	-0.17	-0.63	0.53	-0.67	0.68*
HI															-0.13	0.35	-0.38	0.27	-0.31*	0.48
BM																0.88**	0.96**	0.76	0.84**	-0.63
GY																	0.65	-0.49	0.63*	-0.35
ETd																		0.60	0.96**	-0.85**
WUEd																			-0.94**	0.96**
CumET																				-0.93**

LL-leaf length; LW-leaf width; LA- leaf area; SW-stem weight; LWt-leaf weight; L:S-leaf weight and stem weight ratio; MAT-maturity; PN-panicle number; SN- spikelet number per panicle; SF-spikelet fertility; FLA-flag leaf area; HI-harvest index; OGW-one thousand grain weight; BM-biomass; GY-grain yield; ETd-daily evapotranspiration; WUEd- water use efficiency on daily basis; CumET-cumulative evapotranspiration; WUE; water use efficiency using BM and CumET. * and ** represent significant levels of *$P \leq 0.05$* and *$P \leq 0.01$*, respectively.

Biomass, Daily and Cumulative Evapotranspiration (ET), Water Use Efficiency of Biomass (WUE_B), and Leaf Width

In terms of biomass, significant difference was found only in growth phase and not in variety (Table 2). Biomass increased from vegetative to ripening phase. Herein, 57.81 g of biomass was produced in ripening, 24.06 g in reproductive, and 3.69 g in vegetative phase. As the biomass increases ET also increases, thus ET increased from vegetative to ripening. Vegetative phase had ET value of 3.29 L, 8.64 L for reproductive, and 24.97 L for ripening. However, unlike biomass, there was significant difference in ET among varieties. Hybrid NSIC Rc202H had the lowest ET in all growth phases, 2.24 L, 7.56 L, and 19.65 L in vegetative,

Table 2. Biomass, cumulative evapotranspiration (ET), water use efficiency of biomass (WUE$_B$), daily ET, and leaf width of three irrigated lowland rice varieties in different growth phases under screenhouse condition.

Growth Phase (GP)/ Variety (Var)	Biomass (g)	ET (L)	WUE$_B$ (g L^{-1})	Daily ET (ml d^{-1})	Leaf Width (cm)
Vegetative					
PSB Rc18	4.40	3.78a	1.16b	118.28a	1.00a
NSIC Rc222	3.41	3.84a	0.89c	119.90a	0.86b
NSIC Rc202H	3.26	2.24b	1.47a	112.04a	1.01a
Mean	3.69z	3.29z	1.17z	116.74z	0.95z
Reproductive					
PSB Rc18	23.30	8.15b	2.80a	214.41b	1.29b
NSIC Rc222	27.80	10.20a	2.75a	268.42a	1.24b
NSIC Rc202H	21.08	7.56b	2.78a	198.88b	1.46a
Mean	24.06y	8.64y	2.78x	227.24y	1.33y
Ripening					
PSB Rc18	58.96	25.97b	2.28b	467.61a	1.57b
NSIC Rc222	61.23	29.30a	2.10b	508.83a	1.58b
NSIC Rc202H	53.25	19.65c	2.72a	328.45b	1.80a
Mean	57.81x	24.97x	2.37y	434.96x	1.65x
GP	**	**	**	**	**
Var	ns	**	**	**	**
GP X Var	ns	**	ns	**	ns

* and **, significant at 5 and 1% level, respectively; ns, not significant.
In a column within each growth phase, means followed by a common letter are not significantly different at 5% level by LSD.

reproductive, and ripening, respectively. Its shortest growth duration might be the reason for its lowest ET during vegetative phase because in this phase there was no significant difference in daily ET. On the other hand, NSIC Rc222 had the highest ET in all growth phases with 3.84 L in vegetative, 10.20 L in reproductive, and 29.30 L in ripening phase. For WUE of biomass (WUE$_B$), significant differences were both found in growth phase and variety. Highest WUE$_B$ was found during reproductive (2.78 g L^{-1}) followed by ripening (2.37 g L^{-1}) then vegetative phase (1.17 g L^{-1}). The lower WUE$_B$ at ripening than reproductive phase was due to lower rate of biomass accumulation (24.06 – 57.81 g) which was 2.4 compared to 2.9 of ET (8.64 – 24.97 L). Among varieties, NSIC Rc202H had highest WUE$_B$ during vegetative and ripening. Its shortest growth duration might be the reason for its lowest ET that gave highest WUE$_B$ during vegetative phase because in this phase there was no significant difference in daily ET among varieties. However, there were significant variations in daily ET during reproductive and ripening phases. NSIC Rc202H had comparable daily ET (198.88 ml d^{-1}) to PSB Rc18 (214.41 ml d^{-1}) but lower than NSIC Rc222 (268.42 ml d^{-1}) during reproductive phase. While it had lowest daily ET of 328.45 ml d^{-1} during ripening compared to 467.61 ml d^{-1} of PSB Rc18 and 508.83 ml d^{-1} of NSIC Rc222. This indicates that genotypic water use (ET) and WUE of irrigated lowland rice might be improved not just by considering growth duration. In terms of leaf width, which is the only trait that reduced ET and increased biomass and WUE (Table 1), significant variations were both found in growth phases and varieties (Table 2). Leaf width increased from vegetative to ripening. Hybrid NSIC Rc202H with highest WUE$_B$ and lowest cumulative and daily ET had also widest leaf width during ripening with 1.80 cm. It had also widest leaf width during reproductive phase with 1.46 cm. On the other hand, leaf width of PSB Rc18 during reproductive (1.29 cm) and ripening (1.57 cm) were comparable to leaf width of NSIC Rc222 within the same phase, 1.24 cm and 1.58 cm, respectively.

Water Use Efficiency of Grain Yield

NSIC Rc202H with highest WUE$_B$ had also highest grain yield WUE (WUE$_G$) with 1.73 g grain L^{-1}. Grain yield WUE of PSB Rc18 (1.35 g grain L^{-1}) and NSIC Rc222 (1.28 g grain L^{-1}) were comparable to each other. These values were closed to the range (0.6 – 1.6 g grain L^{-1}) reported by Bouman et al., 2007; Alberto et al., 2011; and Maina et al., 2014. Grain yield, like biomass, had no significant difference among varieties while cumulative ET showed significant variation. NSIC Rc202H with highest WUE$_G$ had lowest cumulative ET (19.65 L) followed by PSB Rc18 (25.97 L) and NSIC Rc222 with highest cumulative ET (29.30 L). For maturity, NSIC Rc202H had shortest growth duration of only 110 days after sowing (DAS). PSB Rc18 and NSIC Rc222 had comparable growth duration to each other with 118 DAS and 119 DAS, respectively. NSIC Rc222 extended its growth duration by five days from the expected 114 DAS (Figure 1).

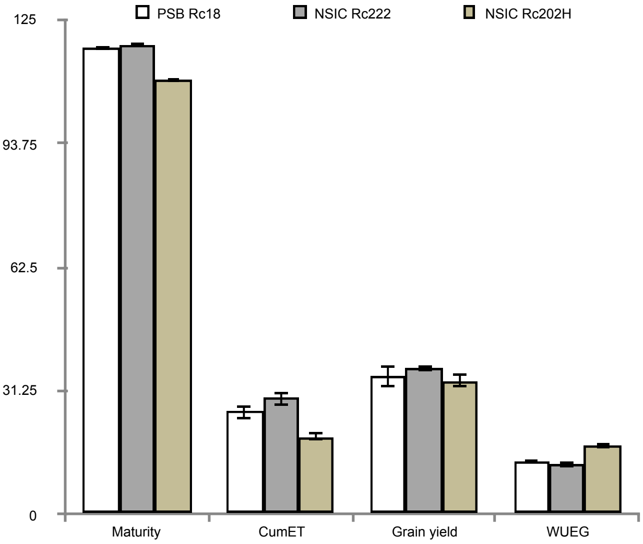

Figure 1. Maturity (days after sowing), cumulative evapotranspiration (CumET, L), grain yield (g plant^{-1}, x 10), water use efficiency of grain yield (WUE$_G$, g grain L^{-1}, x 10) of three irrigated lowland rice varieties under screenhouse condition. Data shown are means ± SD of three replications.

DISCUSSION

This study was able to identify plant trait – leaf width with strong negative correlation to cumulative ET (r = -0.76) and at the same time very strong positive relationship to biomass (r = 0.87) and WUE (r = 0.88) (Table 1). Thus, broad leaf might contribute to the reduction of water use (ET) and improvement of biomass production and WUE of irrigated lowland rice varieties. The measured leaf width of the varieties tested ranged from 0.86 – 1.80 cm from vegetative to ripening phase (Table 2). Broader leaves may contribute to better covering of soil surface reducing evaporation and have larger boundary layer that can partially reduce transpiration (Yates et al., 2010), thus reducing ET. During ripening phase, NSIC Rc202H had the broadest leaves and lowest daily and cumulative ET, hence highest WUE (Table 1). Also, broader leaves contribute to higher light interception (Yoshida, 1981), thus higher canopy photosynthesis for higher biomass production. Other reported traits such as high culticular wax, numerous leaf hair and vertical leaf angle can indirectly reduce transpiration by lowering leaf temperature (Lambers et al., 2008). On the other hand, long leaf length, large leaf and flag leaf area, high spikelet fertility, heavy grain weight and early maturity were found to reduce ET and increase WUE. It is interesting to note that leaf dimension had at least strong negative relationship to cumulative ET but had at least positive strong relationship to WUE. In this set-up, wherein plants had wider spacing, as the leaf area increases water use decreases. This might be due to reduction in evaporation with larger canopy by providing more cover to soil surface. Also, better control of water loss by stomata than water loss through evaporation particularly when evaporating power of the atmosphere is high. Moreover, since leaf is the main photosynthetic organ of the plants, high leaf area will increase biomass (Yoshida, 1981), thus further increasing WUE.

Biomass and grain yield did not vary while ET showed significant difference among varieties. As the biomass increases from vegetative to ripening phase amount of ET also increases. The rate of increase in biomass was higher in vegetative – reproductive while rate of increase in ET was higher in reproductive – ripening. Hence, highest WUE among growth phases was found in reproductive phase. During vegetative phase wherein daily ET of varieties had no variation, there was a significant difference for cumulative ET indicating the effect of growth duration to water use (ET). However, the result of daily ET under reproductive and ripening showed variations among varieties indicating the possibility of reducing ET not just by early maturing variety (growth duration). Other traits that can be considered aside from early maturing and broad leaf are long leaf length, high spikelet fertility and heavy grain weight to reduce ET and increase WUE. The findings of this study, however, particularly on the effect of broad leaves should be verified under field condition because of the faster wind speed that can reduce or eliminate the effect of boundary layer in transpiration.

CONCLUSION

Among agro-morphological traits that were evaluated, only broad leaf was identified with consistent effects of decreasing ET while increasing biomass and WUE. Broad leaves have higher boundary layer and contribute to better covering of soil surface both of which reduce ET, and contribute to higher light interception for higher biomass production, hence high WUE. Other traits such as long leaf length, high spikelet fertility, heavy grain weight and early maturity decreased ET while increased WUE. Hence, these traits can be considered by breeders to improve the WUE of irrigated lowland rice varieties. On the other hand, reproductive phase was identified to have highest WUE; the lower WUE of ripening than reproductive phase was due to lower rate of increase of biomass than ET from reproductive to ripening phase. Hybrid NSIC Rc202H with broadest leaves and shortest growth duration was identified to have highest WUE than inbreds NSIC Rc222 and PSB Rc18.

ACKNOWLEDGEMENT

The authors would like to thank the Institute of Biological Sciences, University of the Philippines Los Baños (IBS-UPLB) for providing the facilities for this study.

CONFLICTS OF INTEREST

The authors declare no conflict of interests.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

AMLA conducted the study, analyzed the data, and prepared the manuscript for publication. NMC helped in conceptualization of the study and revision of the manuscript.

REFERENCES

Alberto MCR, Wassmann R, Hirano T, Miyata A, Hatano R, Kumar A, Padre A, Amante M. 2010. Comparisons of energy balance and evapotranspiration between flooded and aerobic rice fields in the Philippines. Agricultural Water Management 98 (2011) 1417-1430

Baker R, Levine G. 2012. Water productivity in context: The experiences of Taiwan and Philippines over the past half-century. Colombo, Sri Lanka: International Water Management Institute. 33p. (IWMI Research Report 145).doi: 10.5337/2012.206

Bureau of Agricultural Statistics. 2014. Retrieved: December 12, 2014 from the World Wide Web: http://www.bas.gov.ph

Blum A. 2005. Drought Resistance, Water use efficiency, and yield potential – are they compatible, dissonant, or mutually exclusive? Australian Journal of Agricultural Research 56:1159-1168

Bouman BAM, Lampayan RM, Tuong TP. 2007. Water management in irrigated rice: Coping with water scarcity. Los Baños (Philippines): International Rice Research Institute. 54 p.

Facchi A, Gharsallah O, Chiaradia EA, Bischetti GB, Gandolfi C. 2013. Monitoring and modelling evapotranspiration in flooded and aerobic rice fields. Procedia Environmental Sciences 19:794-843

Jose AM, Cruz NA. 1999. Climate change impacts and responses in the Philippines: Water resources. Clim Res 12:77-84

Kang Y, Khan S, Ma X. 2009. Climate change impacts on crop yield, crop water productivity and food security – A review. Progress in Natural Science 19:1665-1674

Lage M, Bamouh A, Karrou M, El Mourid M. 2003. Estimation of rice evapotranspiration using a microlysimeter technique and comparison with FAO Penman-Monteith and pan evaporation methods under Moroccan condition. Agronomie 23:625-631

Lambers H, Chapin FS, Pons TL. 2008. Plant Physiological Ecology (2nd ed). 604p

Philippine Atmospheric, Geophysical and Astronomical Services Administration. 2014. Retrieved: December 12, 2014 from the World Wide Web: http://www.pagasa.dost.gov.ph

Peng S, Khush GS, Virk P, Tang Q, Zou Y. 2008. Progress in ideotype breeding to increase rice yield potential. Field Crops Research 108: 32-38

Prasad PVV, Boote KJ, Allen LH, Sheehy JE, Thomas JMG. Species, ecotype and cultivar differences in spikelet fertility and harvest index of rice response to high temperature stress. Field Crop Research 95:398-411

Philippine Rice Research Institute. 2014. Retrieved: December 12, 2014 from the World Wide Web: http://www.philrice.gov.ph

Republic of the Philippines Water Situation Report. 2006. A project of the League of Cities of the Philippines

Tuong TP, Bhuiyan SI. 1999. Increasing water use efficiency in rice production: Farm-level perspectives. Agricultural Water Management 40:117-122

Wailes EJ, Chavez EC. 2012. ASEAN and global rice situation and outlook. ADB Sustainable Development Working Paper Series.Series No. 22. August 2012

Wang W, Sun F, Luo Y, Xu J. 2012. Changes of rice water demand and irrigation water requirement in Southeast China under future climate change. Procedia Engineering 28:341-345

Yang CM. 1994.Response of rice yield in relation to solar radiation and air temperature under soil water deficit. Chinese Journal of Agrometeology 1(1): 27-34

Yates MJ, Verboom GA, Rebelo AG, Cramer DM. 2010.Ecophysiological Significance of Leaf Size Variation in Proteaceae from the Cape Floristic Region. Functional Ecology 24(3):485-492

Yoshida S. 1981. Fundamentals of Rice Crop Science. International Rice Research Institute. Los Baños, Philippines. 269 p.

Yoshida S, Forno DA, Cock JH, Gomez KA. 1976. Laboratory Manual for Physiological Studies for Rice. International Rice Research Institute. Los Baños, Philippines. 83 p.