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

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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.
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, 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 Banos (IBS-UPLB), Los Banos, 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 (Tabigue 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 (Als) 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 R202H, 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.

\[
\text{Daily ET in vegetative phase} = \frac{\text{Cumulative ET from transplanting to PI}}{\text{Number of days from transplanting to PI}}
\]

\[
\text{Daily ET in reproductive phase} = \frac{\text{Cumulative ET from PI to flowering}}{35 \text{ days}}
\]

\[
\text{Daily ET in ripening phase} = \frac{\text{Cumulative ET from flowering to maturity}}{30 \text{ days}}
\]

**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 panicle), 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 (WUEa) and grain yield (WUEc) for each variety was computed. For WUEa during vegetative, reproductive, and ripening phases were computed using Equations 4, 5, and 6, respectively, while equation 7 was used to compute WUEc.

\[
\text{WUEa in vegetative phase} = \frac{\text{Biomass in PI}}{\text{ET from transplanting to PI}}
\]

\[
\text{WUEa in reproductive phase} = \frac{\text{Biomass in flowering}}{\text{ET from transplanting to flowering}}
\]

\[
\text{WUEa in ripening phase} = \frac{\text{Biomass in maturity}}{\text{ET from transplanting to maturity}}
\]

\[
\text{WUEc} = \frac{\text{Grain yield at} 14\% \text{ moisture content}}{\text{ET from transplanting to maturity}}
\]

**Statistical analysis**

Analysis of variance (ANOVA) appropriate to split-plot RCBD was used. Comparison among means was done using least 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 Bioinformatics Group of Plant Breeding, Genetics and Biotechnology Division (PGBDB) of International Rice Research Institute (IRRI).
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 (WUEb), significant differences were both found in growth phase and variety. Highest WUE was found during reproductive (2.78 L\(^{-1}\)) followed by ripening (2.57 L\(^{-1}\)) then vegetative phase (1.17 L\(^{-1}\)). The lower WUE at ripening than reproductive phase was due to lower rate of biomass accumulation (240.6 – 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 during vegetative and ripening. Its shortest growth duration might be the reason for its lowest ET that gave highest WUE 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. It had the lowest 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 WUEa and lowest cumulative and daily ET had also widest leaf width during ripening with 1.46 cm. It had also widest leaf width during reproductive phase with 1.29 cm. On the other hand, leaf width of PSB Rc18 during reproductive (1.29 cm) and lowest cumulative and daily ET had also widest leaf width during 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 that can 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.

**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 3). 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 culicular 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 canopies 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 broader leaves and shortest growth duration was identified to have highest WUE than inbreds NSIC Rc222 and PSB Rc18.
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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.

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