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Growth, development, yield and harvest index of two diverse rice cultivars in different water regimes and soil textures

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Abstract

Emerging rice cultivars and crop management strategies have to be investigated further with the pressing issues on water shortage for enhanced growth, development and productivity. A pot experiment was conducted in the greenhouse to evaluate the impacts of water regimes (aerobic, saturated and continuous flooding), soil textures (clay and silt loam), and cultivars (Cocodrie and Rondo) including their interactions on rice growth, development, grain yield and harvest index. Normal flowering duration of Rondo was sustained with the presence of floodwater at flowering stage. Grain filling duration was longer in aerobic water regime under silt loam soil. Longer maturity in aerobic water regime was affected by water stress during grain filling stage and not at early vegetative stage until flowering. Grain yield of Rondo was higher by 22% and had greater plant height, tiller count and biomass when planted in clay soil. Harvest index of Cocodrie was higher by 70% compared to Rondo. Grain yield of Rondo was best if flooded continuously while Cocodrie can equally produce grain in aerobic, saturated and flooded water regimes. Growing Cocodrie in clay soil with aerobic water regime is a good option to save more water without significant yield losses. With foreseeing drought and limited water supply for rice production, our study suggests that water regime is the major factor to be considered before selecting rice cultivars to be grown at varying soil textures.

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Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and it is grown widely in six continents, largely in Asia. It is the staple food for more than half of the world's population and is now a commodity of strategic significance driven by changing food preference in the urban and rural areas and compounded by increased urbanization (Khalil *et al.*, 2009). The looming water crisis for rice production becomes aggravated as population continuously grows and climate is unfavourably changing.

To alleviate the problem of water shortages in rice production areas, several technologies have been developed to reduce water use and increase crop water productivity. These include the use of saturated soil culture (Borell *et al.*, 1997), alternate wetting and drying (Li, 2001; Tabbal *et al.*, 2002), ground cover systems (Lin *et al.*, 2002), system of rice intensification (Stoop *et al.*, 2002), and aerobic rice (Bouman *et al.*, 2002). Being a water loving crop, rice in fields are still kept flooded for some periods in most of these systems, so water use remains high. Likewise, these technologies can sometimes lead to some yield penalty, if the existing irrigated lowland rice cultivars are used. Aerobic rice is one of the most promising alternative systems, since rice plants are grown in non-puddled and non-saturated soils, thereby reducing irrigation requirements especially during land preparation (Tuong *et al.*, 2005). However, previous studies often reported a significant reduction in rice yield in aerobic culture compared with flooded culture even when the soil was maintained near field capacity (Belder *et al.*, 2005; Peng *et al.*, 2006). The yield reduction of aerobic rice was attributed more to changes in biomass production than in harvest index especially when aerobic rice was continuously grown and the decline was greater in the dry cropping season. As stated by Sikuku *et al.* (2012), plant height and biomass accumulation were more sensitive to water deficit occurring at vegetative stage as compared to water deficit occurring at reproductive stage. Water deficit has been described as the single physiological and ecological factor upon which plant growth and development depends more heavily than other factors.

Similarly, soil textures plays critical roles in terms of enhancing rice crop growth and development that will lead to improved productivity. Soil texture and structure affects crop root growth which considered as a main organ responsible for water and nutrient uptakes. Bigger roots have greater potential in elongation that can enhance better water and nutrient uptake, and overall root production. Root growth as well as biomass accumulation of the same cultivar can vary with soil texture and water management scheme. Also, clay soil contains more organic matter than sandy soil because of greater physical protection attributed from clay (Parton *et al.*, 1987). Higher content of organic matter generally means higher available water capacity (AWC). After a critical review, Hudson (1994) reported that as soil organic matter content increased from 0.5 to 3%, AWC of the soil is more than doubled. In the same manner, loss of organic matter coupled with soil compaction can significantly reduce crop yield (Powers *et al.*, 2005). Therefore, it is critical to determine the impacts of soil properties on different production systems related to water regime along with rice cultivar.

Rice breeding over the last decade has increased water productivity by increasing yields together with reducing crop growth duration, and hence reducing seasonal transpiration (Tuong, 1999). Grain yield is characterized by (a) the amount of biomass produced by photosynthesis, and (b) the amount of biomass partitioned to grains, usually expressed as harvest index (HI). Most of the increases in rice yield in the last decades were achieved by improvement in HI. As reported by Richards *et al.* (1993), HI may now be approaching its theoretical limit while there is little difference in photosynthetic rate among different commonly grown rice cultivars. Peng *et al.* (1998) reported that biomass production per unit water transpired was some 25 to 30% higher for tropical japonica than for indica rice. Several studies suggest that suitable rice cultivars and crop management strategies have to be investigated further to enhance growth, development and productivity of rice using less water. Therefore, this study was conducted to evaluate the effect of water regimes, soil textures and cultivars including their interactions on rice phenology, growth, development, grain yield and harvest index through a pot experiment in the greenhouse.

Materials and methods

The pot experiment was established at the temperature and relative humidity controlled greenhouse of the Texas A & M AgriLife Research Center in Beaumont, Texas. The experiment was arranged in a split-plot design composed of three factors *viz.* water regimes, soil textures and rice cultivars with three replications. Specifically, water management option as main factor had three water regimes *viz.* aerobic, saturated and continuous flooding. Clay (from Beaumont Center) and silt loam (taken at Eagle Lake station) soil textures, and Rondo and Cocodrie rice cultivars were used as sub factors in the experiment with complete randomization.

Water regimes

The three water regimes have known as water management options for rice production. Soils were kept moist in all experimental pots from seeding until imposing water regimes starting week 3 or 12 days after germination (DAG). Under aerobic, water was applied inside the box at around 2 cm depth when soil suction reading reached at 40 kPa to bring the soil nearly at field capacity from week 3 to booting stage and from grain filling stage to terminal irrigation. Floodwater depth of 3 to 5 cm from the soil surface was maintained at booting to flowering stage in aerobic. For saturated, water level in the wooden box was maintained at 2 to 5 cm below the soil surface in the pots to continuously saturate the soil until terminal irrigation. Floodwater depth of 3 to 5 cm from the soil surface was kept in continuous flooding from week 3 to terminal irrigation. Water from each box was removed 2 days before crop cutting at harvest. The two cultivars have different maturity but were put together in each box set for a water regime from start of the experiment. Thus, to facilitate final data gathering, the pots with similar cultivar under the same water regimes were re-arranged and grouped 10 days before terminal irrigation. Terminal irrigation was done a week before harvest.

Soil textures

The two soil types were obtained in research fields of two locations, Beaumont and Eagle Lake. The soil at Beaumont was a League clay soil (fine, montmorillonitic, Entic Pelludert) and the soil at Eagle Lake was a Hockley silt loam (fine, smectitic, hyperthermic Typic Albaqualfs). The main soil properties measured were listed in Table 1. Briefly, soil texture was measured using a hydrometer procedure (Day, 1965). A 1:2 soil: water extract was used to measure soil pH (Schofield and Taylor, 1955). The soil samples were oven dried at 105°C and finely ground to measure soil organic content (SOC) by combustion using an Elementar Americas Inc, Vario MAX CN analyzer (Mt. Laurel, NJ, U.S.A) (Wight *et al.*, 2012). Soil nitrate was extracted by a 1 M KCl solution and determined by a Cd-reduction method (Kachurina *et al.*, 2000). Other plant available elements including P, K, Ca, Mg, Na and S were extracted using the Mehlich III extractant and were determined by Inductively Coupled Plasma (ICP) (Mehlich, 1984).

Table 1. Main soil properties of the soil samples from Beaumont Center and Eagle Lake Station, Texas.

Soil Texture	Silt (g kg^{-1})	Clay (g kg^{-1})	pH	SOC (g kg^{-1})	Nitrate (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})
Clay	22	64	5.9	12	2	13	267	4716
Silt Loam	16	15	5.9	7	1	36	48	753

Cultivars

The two diverse rice cultivars used were Cocodrie and Rondo, both commercially released cultivars in US. Cocodrie was bred by the Louisiana Rice Research Station at Crowley, LA, and very popular in southern US rice belt (Linscombe *et al.*, 2000) after Cypress. A typical long-grain indica cultivar, Rondo was bred by USDA ARS and had features of high yield potential, an excellent disease resistance package, and premium processing quality (Yan *et al.*, 2010). Rondo and Cocodrie were grown in 18-cm high plastic pots with 12 and 15 cm bottom and top diameters, respectively. Twelve pots were placed in one wooden box (87×87×40 cm) lined with black plastic sheets to keep water and avoid water spill during irrigation throughout the growing period. Water was applied inside the wooden box at 10 cm depth a day before seeding. Pre-germinated seeds were direct-seeded manually by pressing the seeds to around 2 mm deep from the top of the wet soils at 3 to 5 seeds per pot. Thinning was done until 10 days from germination to maintain one seedling per pot. In all pots, phosphorous (P_2O_5) and potassium (K_2O) fertilizers at 67 kg ha^{-1} were applied as basal by incorporating the fertilizers during soil medium preparation both for the two soils. Nitrogen (N) was applied in week 2 (11 DAG), 5 (35 DAG) and 8 (65 DAG) at the rate of 20, 50 and 30%, respectively with the recommended N of 280 kg ha^{-1} for clay soil and 235 kg ha^{-1} for silt loam soil. Hand weeding was done to keep the pots weed-free. Granular insecticides were applied at maximum tillering and flowering stages to avoid panicle mites and other insects infestation.

Destructive sampling, data gathered and analysis

Phenology on flowering duration (days) was recorded from germination to start of flowering, 20, 50, 80 and 100% flowering. Grain filling duration (days) was determined from 100% flowering to the date of harvest. Destructive sequential sampling by cutting one whole plant above the soil was done at booting (BO), grain filling (GF) and harvest (H) to determine the shoot and grain biomass (g plant^{-1}), number of tillers, and plant height (cm). Plant heights were measured from the base of the plant to the tip of the longest leaf (BO) and panicle (GF and H), and the number of tillers per plant was also counted at the same time. Root biomass (g plant^{-1}) was determined only at H using the same plant samples for shoot and grain biomass measurement. Grains were threshed manually before washing and cutting the roots, air dried for three days and weighed separately to determine the grain yield (GY) expressed in g plant^{-1}. Roots were washed using tap water to remove the soil particles, wiped with dry paper towels and cut from the base of the plant. Grain moisture content was determined using digital moisture meter after weighing. GY was adjusted to 12% moisture content. Air dried plant samples including the extracted grains and roots were placed separately in a paper bag and oven dried at 70°C in 72 h. Dry weight of the shoot, grain and root biomass was determined separately after oven drying. Total dry biomass (g plant^{-1}) was calculated based on the aggregated dry weight of shoot, grain and root biomass at H. HI (%) was calculated as the total grain biomass divided by the shoot biomass at H and multiplied by one hundred. Analysis of variance (ANOVA) for a split-split plot was performed to determine main and interaction effects of water regimes, cultivars and soil textures (SAS, 2012). Means with significant effects were compared based on the least significant difference (LSD) test at $P < 0.05$ and correlation coefficients were calculated at $P < 0.05$.

Results and discussion

Rice phenology

Duration of flowering was significantly affected by soil textures and cultivars (Table 2). Significantly longer days to flower of Rondo and silt loam soil were observed compared with Cocodrie and clay soil, respectively (Fig. 1). Water regimes did not affect the number of days to flowering, which indicates that the three water regimes, particularly aerobic water regime did not contribute damaging stress to the rice plant at vegetative stage. It was noticed that floodwater maintained at flowering stage did not affect normal flowering duration, which supports the report of O' Toole (1982) that the most sensitive stage is about 10 days before flowering until 7 days after flowering.

Grain filling duration from 100% flowering to harvest was affected significantly by cultivars and the interaction of water regimes and soil textures (Table 2). Rondo had significantly longer grain filling duration of 3 days compared to Cocodrie. The effects of water regimes on grain filling duration varied with soil textures. Under silt loam soil, grain filling duration increased with water regimes in the order of continuous flooding, saturated and aerobic. Grain filling duration under clay soil was longer at continuous flooding, but grain filling duration among saturated and aerobic water regimes did not differ significantly.

Table 2. Results on statistical significance of different factors and factor interactions on rice phenology, plant height, tiller count, biomass, grain yield and harvest index.

Source of Variance	df	FL_1	FL_{20}	FL_{50}	FL_{80}	FL_{100}	GFD	H	PH-BO	PH-GF	PH-H	TC-BO	TC-GF	TC-H	SB-BO	SB-GF	SB-H	GB-H	RB-H	TDB-H	GY	HI
Water (W)	2	ns	ns	ns	ns	ns	ns	*	**	**	**	ns	ns	**	*	ns	**	**	ns	**	**	ns
Soil (S)	1	**	**	**	**	**	**	ns	*	**	**	ns	ns	**	ns	**	**	**	*	**	**	ns
Cultivar (C)	1	**	**	**	**	**	*	**	**	ns	ns	**	**	**	**	**	**	ns	**	**	**	**
W x S	2	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns
W x C	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	*	ns	**	**	ns	**	**	ns
S x C	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns
W x S x C	2	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error	24																					
Total	35																					

Significance levels: ns, $P>0.05$; *, $P<0.05$; **, $P<0.01$; Phenology (days) at start of flowering (FL_1), 20% flowering (FL_{20}), 50% flowering (FL_{50}), 80% flowering (FL_{80}), 100% flowering (FL_{100}), grain filling duration (GFD) and harvesting (H); Plant height (cm) at booting (PH-BO), grain filling (PH-GF) and harvest (PH-H); Tiller count at booting (TC-BO), grain filling (TC-GF) and harvest (TC-H); Shoot biomass (g plant^{-1}) at booting stage (SB-BO), grain filling (SB-GF) and harvest (SB-H); Grain biomass (g plant^{-1}) at harvest (GB-H); root biomass (g plant^{-1}) at harvest (RB-H); total dry biomass (g plant^{-1}) at harvest (TDB-H); Grain yield (GY) (g plant^{-1}) and harvest index (HI) (%).

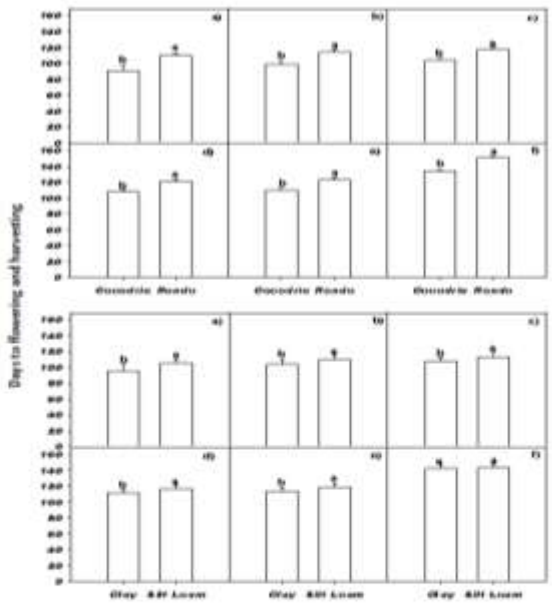

Fig.1. Effect of soil texture and cultivar on the days to flowering at (a) start of flowering, (b) 20% flowering, (c) 50% flowering, (d) 80% flowering, (e) 100% flowering, and (f) harvesting.

Water stress at vegetative stage may not have much effect on the heading time and yield (Pantuwan *et al.*, 2002b). The most sensitive stage to water deficit is at flowering time as the deficit then may cause flowering delay, which has been suggested as an indicator of drought susceptibility. Longer grain filling duration can be attributed to the amount of water in less textured soil and genetic make-up of rice plant for shoot architecture and root system to resist drought than controlled irrigation schemes. Several reports indicated that longer duration or higher rate of grain filling may lead to a higher percentage of filled grains. The percentage of filled grains depends on the grain filling rate and grain filling duration of superior and inferior grains, which may be fast synchronous, slow synchronous, or asynchronous (Yang *et al.*, 2000). In addition, Yang *et al.* (2002) reported that studies with 'super rice' have also shown that asynchronous grain filling results in a lower percentage of filled grains compared to synchronous grain filling. Similarly, Wei *et al.* (2011) revealed that filling of inferior and superior grains of HD297 were quite asynchronous, suggesting that the delay and frequent failure to fill inferior grains limit the yield.

Harvesting period was significantly affected by cultivars and water regimes (Table 2). Late maturity of Rondo may be due late start of flowering coupled with longer grain filling duration. Growing period of the rice plant decreased with water regimes in the order of aerobic, saturated and continuous flooding. Huang *et al.* (2008) reported the same observations from China that rice growth duration was longest under dry cultivation (delayed by 13.5 days compared with continuous flooding), and compared with continuous flooding, intermittent irrigation delayed tillering by 5 to 7 days, reduced the leaf transpiration rate and enhanced the leaf photosynthetic rate. The early crop maturation under direct-seeded rice also helps in reduction of irrigation water requirement (Gill and Dhingra, 2002). This result suggests that severe water stress under aerobic water regime at grain filling stage should be avoided so that grain filling duration and harvesting time will not be prolonged which may need extra irrigation.

Plant height and tiller count

Plants height, which indicated the health and vigor of the rice, was directly proportional to the development of root system, availability of nutrients in the soil and other critical factors controlling plant growth. Plant height at BO, GF and H was significantly affected by water regimes and soil textures (Table 2). Plant height of Rondo and Cocodrie did not differ significantly at GF and H. Significantly higher plant height was determined consistently at BO, GF and H in clay soil, and continuous flooding (Fig. 2). Clay soil had higher plant height by 8% at H compared with silt loam soil. Aerobic water regime had lower plant height during the entire growing period as compared with continuous flooding and saturated which is clearly associated with lesser number of irrigation and applied water. Rondo is slightly taller than Cocodrie with an average plant height at H of 99 cm compared to Cocodrie's 97 cm. These results are consistent with the reports of Islam *et al.* (1994) and Islam (1999) that water stress reduced plant height. Similar findings were reported by Soriano (2008) wherein decreasing irrigation interval and increasing depth of irrigation in rice production produced greater plant height. It was further noted that growth rate was faster at higher depth of irrigation and frequent irrigation interval especially under increasing level of nitrogen fertilizer.

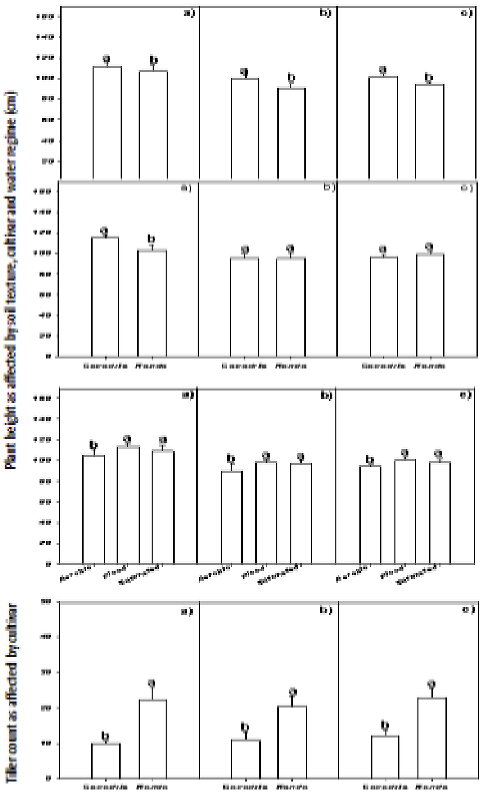

Fig. 2. Soil texture, cultivar and water regime effects on plant height, and effect of cultivar on the number of tiller per plant at (a) booting, (b) grain filling and (c) harvest.

Number of tillers per plant was significantly affected by cultivar at BO, GF and H (Table 2). Rondo had produced consistently more tillers per plant than Cocodrie. Accordingly, there were significant differences on the number of tillers per plant as affected by water regimes and soil textures at H. Continuous flooding and clay soil produced more tillers at H. It is good to note that number of tillers at BO and GF were not affected significantly by water regimes and soil textures. This indicates that the effects of water regimes and soil textures were more evident during reproductive stage than at early growth stages. It was also observed that more tillers were withered at reproductive stage under aerobic water regime and silt loam soil, which can be attributed to limited water supply within the root zones after flowering stage. It was further noted that the number of productive tillers (data not shown) differs significantly at H. Thus, aerobic water regime and more textured soils can produce comparable number of tillers at vegetative stage but both cannot sustain productive tillers until maturity. Lampayan *et al.* (2010) noted the same response in aerobic rice system where more tillers were produced at vegetative stage when the soils were kept aerobic for few days. Differences on these parameters including rice yield are also linked to overall soil fertility and availability of plant nutrients under flooded and non-flooded condition, the latter condition creating an unfavorable nutrient regime for several plant nutrients (Sahrawat, 2012).

The interaction between water regimes and cultivars was found highly significant for tiller number per plant at H (Table 2). Rondo had decreasing number of tillers per plant from continuous flooding to aerobic water regime. Cocodrie, however, had nearly the same number of tillers per plant in all three water regimes. This result indicates that Cocodrie is more flexible in producing tillers at all growth stages under the three water regimes and can be grown in both flooded and non-flooded condition, unlike Rondo that needs continuous flooding to produce more tillers. Likewise, growing Rondo in clay soil showed best results on plant height and tiller count. Results on plant height and tiller count suggest that better option on water regimes at reproductive stage and cultivar must be considered to avoid severe water stress on the plants which may sustain productive tillers until maturity.

Rice biomass

Shoot biomass was significantly affected by cultivars at BO, GF and H; effect of soil textures on shoot biomass was found highly significant at GF and H; and shoot biomass at BO and H was significantly affected by water regimes (Table 2). Shoot biomass of Rondo at BO, GF and H was 50% higher than Cocodrie (Fig. 3i). Clay soil had 31 and 43% heavier shoot biomass than in silt loam soil at GF and H, respectively. Significantly heavier shoot biomass was determined in continuous flooding at BO and H, but no significant difference between aerobic and saturated water regimes at these stages. It was suspected that continuous saturation or flooding from booting to flowering in all water regimes has resulted to insignificant differences on shoot biomass at GF stage. However, due to continued variations on water regimes after 100% flowering, the shoot biomass at H was again varied significantly due to water stress in aerobic water regime. These results are consistent with the findings of Bouman and Tuong (2001) and Lampayan *et al.* (2010) on rice development and dry biomass accumulation under aerobic rice system.

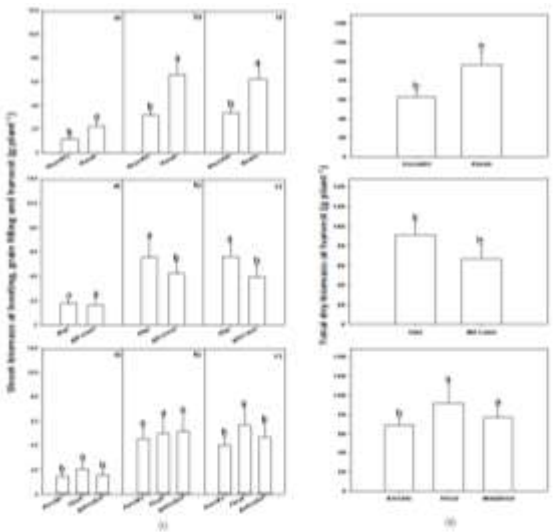

Fig. 3. (i) Effect of cultivars, soil textures and water regimes on shoot biomass at (a) booting, (b) grain filling, and (c) harvest; and (ii) cultivars, soil textures and water regimes effects on total dry biomass at harvest.

The interaction between water regimes and soil textures had significant effect on shoot biomass at BO, while shoot biomass at BO and H was also affected significantly by the interaction between water regimes and cultivars (Table 2). Obviously, effect of water regimes under the different soil textures on shoot biomass is more pronounced at BO and H than at GF, and greater differences occurred at H. This is clear indication that the effects of water regimes on plant growth and development is more pronounced at grain filling stage than at vegetative stage in both clay and silt loam soils. Similar trend on plant height and tiller count was noted as discussed earlier. In contrast, Sikuku *et al.* (2012) stated that plant height and biomass accumulation were more sensitive to water deficit occurring at vegetative stage as compared to water deficit occurring at reproductive stage. Under clay soil, continuous flooding had significantly heavier shoot biomass at H while aerobic water regime had the lowest. Similar result under silt loam soil where continuous flooding had heavier shoot biomass, but shoot biomass produced under aerobic and saturated water regimes did not differ significantly. Rondo had significantly higher shoot biomass when flooding is done continuously while shoot biomass at H of Cocodrie was not affected significantly by water regimes, implying that more shoot biomass is expected when Rondo is grown especially in clay soil under continuous flooding. However, when water is a limiting resource, Cocodrie is a better option to grow under aerobic or saturated water regime without significant decrease on shoot biomass.

Variation on grain biomass at H was affected significantly by water regimes, soil textures, and the interaction between water regimes and cultivars (Table 2). Grain biomass in aerobic and saturated water regimes did not vary but they are significantly lower by 28 to 30% compared to continuous flooding. Clay soil had 47% greater grain biomass compared with silt loam. The interaction effects between water regimes and cultivars on grain biomass were similar with that of shoot biomass at H. Grain biomass of Rondo was higher in continuous flooding but grain biomass of Cocodrie was not affected significantly by water regimes at H.

Root biomass at H was not affected significantly by water regimes but highly affected by cultivars and soil textures (Table 2). Rondo had significantly greater root biomass than Cocodrie. The root biomass in silt loam was 20% greater than in clay soil. Growth and development of the roots might be enhanced by more pore spaces in silt loam without limiting the required nutrients. In clay soil, root biomass decreased with the order from continuous flooding, saturated and aerobic. Effects of water regimes on root biomass did not vary under silt loam soil. The ratio of deep root to total root biomass was higher in direct dry-seeded or aerobic rice compared with continuously flooded and transplanted rice (Kaur *et al.*, 2015). In addition to deeper roots, vigorous adventitious surface rooting would be beneficial in improving N and water uptake efficiencies, especially during reproductive growth stage. To improve root system architecture, Kato and Okami (2010) recently proposed that rice should be genetically improved towards that of dryland crops (i.e. vigorous rooting in the subsurface layer) for adaptation to aerobic culture.

Overall, the total dry biomass at H was significantly affected by soil textures and the interaction between water regimes and cultivars (Table 2). The total dry biomass of Rondo under aerobic and saturated water regimes were 55 and 44% lower than that of continuous flooding, respectively. For Cocodrie, the total dry biomass was higher in continuous flooding but did not vary among aerobic and saturated water regimes. Similar trends were observed on total dry biomass with that of shoot biomass at BO and H, and grain biomass at H as affected by the interaction between water regimes and cultivars. A significant positive correlation between root growth and total biomass production of rice has been reported by Yoshida (1981). With this study, treatments with greater root biomass had higher total dry biomass except for the result of soil textures where root biomass is higher in silt loam with lower total dry biomass at H. Total dry biomass in continuous flooding was higher by 35 and 20% compared to aerobic and saturated water regimes, respectively (Fig. 3ii). Rondo had greater total dry biomass compared with Cocodrie. The significant interaction effects between water regimes and cultivars determined in this study on overall rice biomass indicates that proper selection of cultivar and water regimes combination must be done and grown in most suitable soil textures.

Grain yield and harvest index

Yield response of cultivars varied depending on water regimes as the ANOVA showed a significant interaction between water regimes and cultivars (Table 2). For Rondo, grain yield decreased with water regimes in the order of continuous flooding, saturated and aerobic (Fig. 4). Grain yield of Rondo under aerobic and saturated water regimes were 36 and 32% lower than the grain yield in continuous flooding, respectively. But grain yield of Rondo under aerobic and saturated water regimes had no significant difference. The highest grain yield was 37 g plant^{-1} with Rondo at continuous flooding. Grain yield of Cocodrie was not affected significantly by water regimes, indicating that Cocodrie can be grown in all three water regimes without significant yield differences. In addition, growing Cocodrie in aerobic water regime can save water up to 46% (data not shown) without significant yield loss. Similarly, Kato *et al.* (2009) reported that Cocodrie has no yield reduction when grown in aerobic soil condition. Japanese cultivar 'Takanari' designed for aerobic soils achieved yields greater than 10 t ha^{-1} when grown under aerobic condition. Kato *et al.* (2009) showed that aerobic rice can out-yield current cultivars and recommended that breeding rice for aerobic production system be conducted since current cultivars are all developed for flooded growing condition. Recently, Zhao *et al.* (2010) reported that most of tested rice genotypes bred for tropic aerobic conditions out-yielded check cultivars with 10% higher yield and greater harvest index. Yield increase was attributed to greater drought tolerance and harvest index compared to the conventional lowland or upland cultivars. These results suggest the need of developing rice cultivars appropriate for aerobic system. Likewise, our result indicates that improving water management under aerobic water regime after flowering may eliminate severe water stress at grain filling stage which may produce more grain yield.

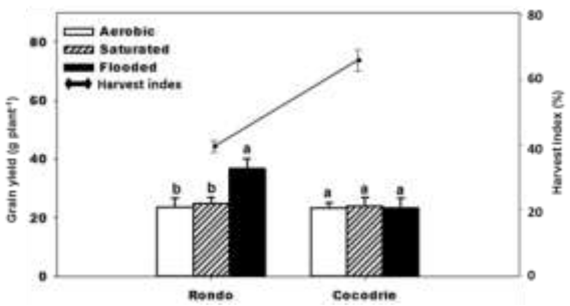

Fig. 4. Cultivars and water regimes effects on grain yield and harvest index at harvest.

Rondo always yielded much higher than Cocodrie in series of yield trials done in flooded fields of Beaumont (R.E. Tabien, personal communication). In this study, grain yield of Rondo was significantly higher by 22% compared to Cocodrie. The grain yield in clay soil was significantly higher (46%) than in silt loam soil. Similar observation was noted in China when cultivars were evaluated in clay and sandy soils (Bouman *et al.*, 2006; Ye *et al.*, 2007) where sandy soil had less yield increase relative to clay soil in varying nitrogen levels (Ye *et al.*, 2007). In a rainfed lowland trial of Thailand, Tsubo *et al.* (2007) also reported that the same response of rice grown in higher clay-content soils had greater grain yield and biomass accumulation than those grown in lower clay content soils. Accordingly, lower grain yield at aerobic water regime may be due to lower plant height, number of tillers and shoot biomass. This result was consistent with the findings of Peng *et al.* (2006) that the yield difference between aerobic and flooded rice ranged from 8 to 69% depending on the number of seasons that aerobic rice has been continuously grown, dry and wet seasons, and cultivars. When the first-season aerobic rice was compared with flooded rice, the yield difference was 8 to 21%. The yield difference between aerobic and flooded rice was attributed more to difference in biomass production than to harvest index.

Harvest index was affected significantly by cultivars but not by water regimes and soil textures (Table 2). Higher total dry biomass and grain yield of Rondo have not resulted to higher harvest index unlike in Cocodrie with higher HI (Fig. 4), indicating that Cocodrie can produce more grain biomass per unit weight of developed shoot biomass at H. Water regimes, soil textures, and interactions with all treatments did not affect significantly the HI, revealing that higher grain yield under clay and continuous flooding was attributed more on the difference of total dry biomass than in harvest index. Under limited water supply situation, it can be concluded that higher harvest index can be achieved using drought resistant rice cultivars with vigorous growth and capable to sustain productive tillers until maturity.

Conclusion

Rondo and Cocodrie cultivars had significant differences on plant height, tiller count, rice biomass, grain yield and harvest index including phenological events on flowering and grain filling duration. Indicative response of soil textures and cultivars was determined in flowering and grain filling duration, plant height, rice biomass and grain yield. Longer maturity in aerobic water regime that received extra irrigation was affected by water stress during grain filling stage and not at early vegetative stage up to flowering. Growing Cocodrie in silt loam soil following either continuous flooding or aerobic water regime can produce more tillers, unlike Rondo that needs continuous flooding to sustain vigorous growth with more productive tillers. Better option on water schemes at grain filling stage must be imposed to sustain vigorous growth and productive tillers until maturity. The interaction between water regimes and cultivars with respect to rice biomass and grain yield support the needs for proper selection of water regime and suitable rice cultivar. Aerobic water regime must be avoided if Rondo or Cocodrie will be grown in silt loam soil. Effects of water regimes on plant growth and development was obvious more at grain filling stage than at vegetative stage in both soil textures. In areas where there is water shortage, combining continuous flooding to aerobic water regime after flowering until physiological maturity can produce stable productive tillers, grain yield and harvest index.

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