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Traditional Upland Rice (*Oryza sativa* L.) for Drought Adaptation in Marginal Uplands

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Abstract

Marginal upland rice ecosystem is threatened by persistent climatic changes such as drought. Upland rice has shallow root systems. Thus, it is more susceptible to drought resulting in lowering yield. The existing traditional (Dinorado, Speaker, and Cabuyoc) and improved (UPL Ri-5 and IR 55419) upland rice varieties were evaluated and characterized at Misamis Oriental State College of Agriculture and Technology research station (dry season) in 2010. A similar study was conducted in 2011 inside the rain shelter at the nursery area of the Department of Agriculture, Baungon, Bukidnon, Philippines. In 2012, one traditional upland rice (Speaker) variety and one improved (IR 55419) upland rice variety were physiologically characterized. The traditional upland rice 'Speaker' produced comparably higher grain yield with the improved upland rice variety IR 55419 outperforming the improved check variety UPL Ri-5 and two other traditional upland rice varieties, 'Dinorado' and 'Cabuyoc', respectively. The yields of 'Speaker' and improved variety IR 55419 were consistently higher even subjected to drought induction. 'Speaker' maintained a higher dry matter accumulation before and after heading, and shoots and roots dry weight throughout the growth period. Moreover, 'Speaker' maintained higher relative chlorophyll content and relative growth rate (RGR) before and after heading. The higher RGR in 'Speaker' was attributed to the higher net assimilation rate (NAR) and larger leaf area before and after heading than in IR 55419. The maintenance of higher relative chlorophyll value and higher NAR in 'Speaker' suggest its potential characteristics in improving marginal upland rice variety.

Keywords: agriculture, assimilation, chlorophyll, varieties, yield

Introduction

Traditional upland rice (*Oryza sativa* L.) is one of the main staple crops in the upland production system in the Philippines and Asia (Portilla & Mirandilla, 2013; Nguyen et al., 2015). However, traditional upland rice is mostly grown in marginal upland areas with highly degraded, infertile and acidic soils. Traditional upland rice is usually aromatic, tall and late maturing, and is usually grown organically, with lesser cultural practices or management intervention. These practices resulted in its lower yield, thus, treated only as subsistence crop (Atlin et al., 2006).

A recent report showed that the trend in the per capita rice consumption (PCRC) in the Philippines is increasing, opposite to the decreasing trend in other ASEAN countries (Francisco et al., 2013). Hence, the Philippine government is promoting upland rice farming in every region of the country to augment the total national rice production. This is an important government initiative towards the goal of rice sufficiency. Also, this provides an opportunity to solve the household-based food security, income, and nutrition of impoverished upland rice farmers in the community (Bernier et al., 2008). However, upland farmers are still living below the poverty line due to lower yield and income (Portilla & Mirandilla, 2013). The lower yield of upland rice due to drought can be augmented by using drought tolerant, location specific, high-yielding traditional and improved upland rice varieties. These can be effectively achieved by using direct selection method for yield under drought stress (Venuprasad et al., 2007; Dixit et al., 2014).

Continued climatic changes threaten the upland rice production (Lin et al., 2015). These changes include erratic rainfall and high temperature resulting in drought condition. Drought is the major abiotic stress affecting upland rice production. Upland rice has shallow root systems and is usually grown in infertile soil, hence, it becomes more susceptible to drought than other crops (Bernier et al., 2008; Dixit et al., 2014).

Several studies demonstrated the use of managed drought stress to increase the heritability of yield under stress similar to those obtained in non-stress conditions (Venuprasad et al., 2007; Dixit et al., 2014;

Trijatmiko et al., 2014; Mickelbart et al., 2015). Those drought-tolerant upland rice varieties can be bred by directly selecting for yield in stress agro-ecosystems. Upland rice varieties have different drought induction responses (Kumar et al., 2008). Therefore, there is a need to evaluate the performance of upland rice varieties, and select the promising drought tolerant germplasm for future breeding and development of drought tolerant rice varieties (Taylaran et al., 2013). This study evaluated the physiological and agronomic performance of existing traditional (native) upland rice including elite upland rice varieties to determine the promising drought tolerant varieties for drought adaptation in marginal uplands.

Materials and Methods

Plant materials and cultivation of rice plants

The experiment was conducted at Misamis Oriental State College of Agriculture and Technology (MOSCAT) Research Station, Claveria, Misamis Oriental in the dry season of 2010. MOSCAT is located at $8^0$36’36” North latitude, $124^0$53’00” East longitude at an elevation of about 615 meters above sea level. The soil type is Jasaan clay with soil pH of 5.29. It has about 2% organic matter, about 69 ppm of Phosphorus, and has sufficient amount of Potassium. Three existing traditional upland rice varieties (Dinorado, Speaker, and Cabuyoc) and two improved upland rice varieties (UPL Ri-5 and IR 55419) were used. Seeds were sown directly in a 4 m x 3 m plot at a planting distance of 0.30 m between rows and 0.20 m between hills with a seeding rate of approximately ten seeds per hole. Seedlings were thinned to approximately four seedlings per hill. No synthetic chemical fertilizers and pesticides were applied. Only organic material (vermicompost) was applied at the rate of five tons/ha. The experiment was laid out in a randomized complete block design (RCBD) with three replicates.

In the dry season of 2011, the same study was conducted, but it was inside the rain shelter at the Nursery Area of the Department of Agriculture, Baungon, Bukidnon, Philippines. The same varieties were used except for UPL Ri-7 instead of ‘Cabuyoc’. Pre-germinated seeds (5 seeds) were planted in a 7” x 11” polyethylene bags and thinned to two healthy seedlings per polyethylene bag. The seedlings were subjected to different duration of drought induction. The study was arranged following a split-split plot design with five replications. The induction of drought at vegetative and at heading stages served as the main plot, while the duration on drought induction served as the sub-plot, while the five upland rice varieties were served as the sub-sub plot.

In the dry season of 2012, one traditional (Speaker) and one improved (IR 55419) upland rice varieties were used based on their performance in the previous experiments. Pre-germinated seeds were sown in 10-L pots filled with a mixture of garden soil and compost soil (1:1, v/v) at three hills per pot density with six to eight pre-germinated seeds per hill. Seedlings were thinned to approximately three seedlings per hill. Organic material (vermicompost) was applied at approximately 200 g per pot before planting and 100g at the maximum tillering stage, respectively. Synthetic chemical fertilizer (46-0-0) of about five grams per pot was applied as supplementation at panicle initiation stage. The experiment was set down in a complete randomized design with five replications in an open field.

Measurements of dry weight and grain yield

The number of stems was counted for a total of 20 hills for each replicate, and then three hills with an average number of stems were selected for the measurements of dry weight at heading and harvest in the field experiment. For the polyethylene bags and pot-grown plants, five polyethylene bags and pots per variety were randomly selected at 30 days after emergence (DAE), 60 DAE at heading, 25 days after heading and at harvest. Plants were separated into parts [leaves, leaf sheaths plus stems, and panicles (from heading)]. Each group of plant parts was dried in a ventilated oven (DY610C Yamato Scientific Chongquing Co., LTD) at 80 ^{0}C for more than four days or to constant weight. The grains were harvested at approximately 85% maturity, and the grain yield was expressed in ton per hectare basis adjusted to 14% moisture content.

Measurement of leaf area and leaf area index

The leaf area of the main stem of the sample plants was estimated based on the length-width method (Yoshida, 1981) using the formula:

$$\text{Leaf area} = k \times l \times w$$

where *k* is the "adjustment factor", *l* is the length, and *w* is the maximum width of the leaf. The *k* value of 0.67 was used during seedling and maturity stages while 0.75 was used in other growth stages. After measuring the leaf area, the leaves were oven dried. All green leaves of the remaining tillers per pot were removed, and oven dried.

The leaf area per hill was determined using the formula:

$$\text{Leaf area/hill} = \frac{aW}{w}$$

where *a* is the total area of sample main stem, *w* is the dry weight of leaves from sample main stem, and *W* is the dry weight of all leaves in the hill including those from the sample main stem.

Leaf area index (LAI) was determined using the formula:

$$\text{LAI} = \frac{\text{the sum of the leaf area per hill (cm}^{-2}\text{)}}{\text{area of land covered per hill (cm}^{-2}\text{)}}$$

Measurement of relative growth rate and net assimilation rate

The relative growth rate (RGR) and the net assimilation rate (NAR) were determined using the following formula (Hunt et al., 2002):

$$\text{RGR (mg day}^{-1}\text{ hill}^{-1}) = \frac{LnW_2 - LnW_1}{T_2 - T_1}$$

$$\text{NAR (mg cm}^{-2}\text{ day}^{-1}) = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{LnLA_2 - LnLA_1}{LA_2 - LA_1}$$

where Ln is natural logarithm, W_2 is the dry weight at time T_2, W_1 is the dry weight at time T_1, LA_2 is the leaf area at time T_2, and LA_1 is the leaf area at time T_1, respectively.

Measurement of relative chlorophyll content

The upper fully expanded leaf of three main stem plants per pot at one month after emergence and two months after emergence were used while the flag leaf and 3rd leaf were used for the measurement of relative chlorophyll value using SPAD chlorophyll meter (SPAD-502, Minolta, Japan). The procedure was done at booting stage, heading stage, one week after heading, two weeks after heading, and at three weeks after heading, and recorded as a mean of six measurements for each selected individual leaf between 9:00 am and 2:00 pm.

Statistical analysis

The two-way analysis of variance (ANOVA) was the statistical tool used to detect the difference among treatments. Tukey’s test (0.05) and *t*-test (0.05) were used to analyze the significant difference between treatment means using the Assistat 7.7 beta software.

Results and Discussion

Comparisons of grain yield, dry matter accumulation, and harvest indices

The productivity of rice farming in the Philippines is driven primarily by irrigation, hybrid, and third generation modern inbred rice varieties and certified seeds, mainly lowland rice (Bordey & Nelson, 2012). The inputs are the non-conventional. However, the yield of traditional upland rice is low because most of the upland rice-growing areas are acidic and infertile. Most traditional rice varieties in upland are tall, low-tillering, and prone to lodging when grown under conditions of favorable moisture and high-soil fertility (Atlin et al., 2006). The traditional upland rice varieties produced heavier dry matter than improved varieties even under upland rice-maize cropping system in acidic upland soil (Mercado et al., 1993). In this study, the traditional upland rice variety 'Speaker' produced comparably higher grain yield with the improved upland rice variety IR 55419 outperforming the improved UPL Ri-5 and two other local varieties, 'Dinorado' and 'Cabuyoc', respectively. 'Speaker' produced heavier dry matter weight at harvest among the selected upland rice varieties (Table 1), which was followed by 'Cabuyoc', 'Dinorado' and IR 55419 while UPL Ri-5 produced the least. Traditional upland rice variety has lower harvest index (Yoshida, 1981; Taylaran et al., 2009; George et al., 2001). In this study, harvest index was also lowest in 'Cabuyoc' while highest in IR 55419 variety. Moreover, there were no significant differences among UPL Ri-5, 'Dinorado', and 'Speaker', although the harvest index in UPL Ri-5 tended to be higher. The higher dry matter production and not the harvest index might be attributed to the higher grain yield in 'Speaker'. However, the higher grain yield in IR 55419 might be associated with the higher harvest index.

Table 1. Grain yield at 14.5% moisture content, dry matter weight at harvest, and harvest index of selected upland rice varieties under field condition grown during the dry season in 2010.

Upland rice variety	Grain yield (t/ha)	Dry weight at harvest (t/ha)	Harvest index (%)
UPL Ri-5	2.18^{b}	9.21^{d}	29.22^{ab}
IR 55419	3.02^{a}	9.80^{cd}	35.93^{a}
Dinorado	2.20^{b}	11.25^{c}	24.13^{bc}
Cabuyoc	2.20^{b}	13.63^{b}	19.91^{c}
Speaker	3.16^{a}	15.86^{a}	23.14^{bc}

Means with the same letter superscript within a column are not significantly different from each other at 5% level by Tukey's test.

The screening and selection of varieties for higher grain yield under managed drought stress are more likely to be more useful in developing drought tolerant varieties (Kumar et al., 2008). It has been demonstrated that drought stress imposed periodically has been shown to increase the heritability of yield under stress to values similar to those obtained for yield in well-watered conditions (Bernier et al., 2008). However, drought stress is very critical in rice at reproductive stage (Venuprasad et al., 2007). The present study obtained similar results when drought was induced at an earlier growth stage and shorter duration (Table 2). As the length of drought induction increases, the yield obtained in upland rice decreases. Among the upland rice subjected to drought induction, IR 55419 obtained comparably higher yield with 'Speaker'. These results indicate that IR 55419 and 'Speaker' could be the potential promising varieties for drought adaptation in marginal uplands.

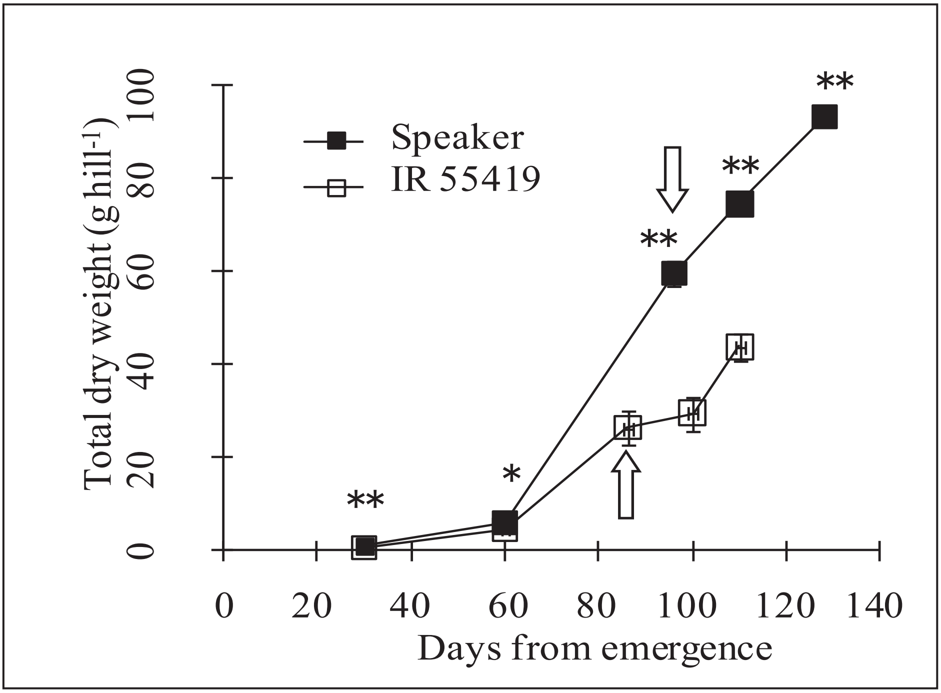
Table 2. Grain yield of selected upland rice varieties in response to stages and duration of drought induction under rain shelter condition in 2011.

Treatments	Grain yield (t/ha)
Stages of Drought Induction	
Drought induction at vegetative stage	2.47[a]
Drought induction at heading (50%)	2.42[b]
Duration of Drought Induction	
Control (No drought induction)	3.43[a]
One week drought induction	3.39[a]
Two weeks drought induction	1.95[b]
Three weeks drought induction	1.00[c]
Upland Rice Varieties	
UPL Ri-5	2.44[bc]
UPL Ri-7	2.36[c]
IR 55419	2.47[ab]
Speaker	2.54[a]
Dinorado	2.41[bc]

Means with the same letter superscript are not significantly different from each other at 5% level by Tukey's test.

Analysis of differences in dry matter accumulation

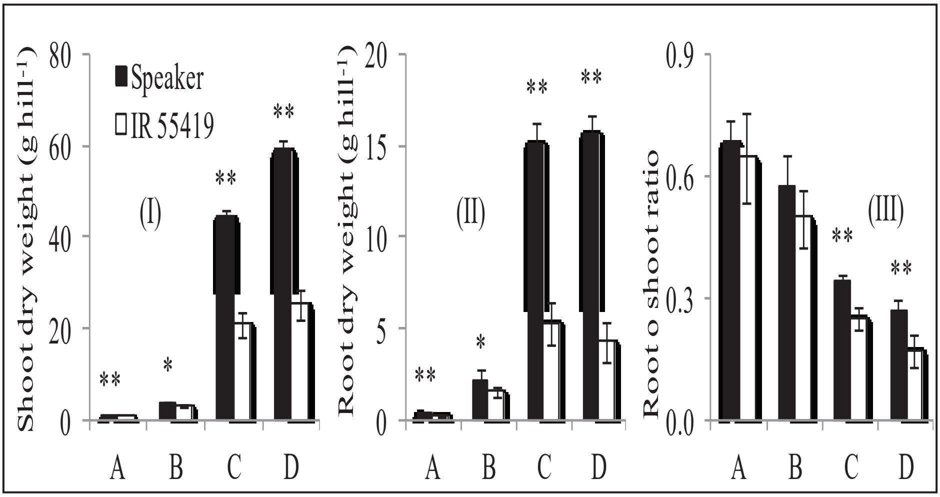
The superiority of the traditional upland rice variety 'Speaker' in total dry matter production appeared as the growth progressed from thirty (30) days after emergence and was maintained through ripening (Figure 1). The traditional variety 'Speaker' consistently produced higher dry matter before and after heading among the upland rice varieties suggesting its potential for marginal uplands.



* indicates significant difference at 5% level of probability by *t*-test.
** indicates significant difference at 1% level of probability by *t*-test.

Figure 1. Changes in total dry weight from approximately one month after emergence to the harvest of pot-grown traditional (Speaker) and improved (IR 55419) upland rice varieties in 2012. Arrows indicate heading stage of 'Speaker' and IR 55419, respectively.

The significant shoot dry weight was observed in 'Speaker' from one month after emergence and was also maintained through ripening (Figure 2-I). Moreover, significant root dry weight was also observed in 'Speaker' from one month after emergence to the ripening stage (Figure 2-II). However, 'Speaker' only revealed significantly higher root to shoot ratio at heading to two weeks after heading although it tended to be higher before heading than the IR 55419 (Figure 2-III). Greater root plasticity concerning nodal root production and elongation and branching is an essential trait for plant adaptation which is an important consideration in breeding high-yielding rice suited to drought-prone environments (Suralta et al., 2012). The larger root surface area in rice might be attributed to the higher nitrogen uptake and hydraulic conductance owing to its higher rate of photosynthesis, thus higher dry matter production (Taylaran et al., 2011).

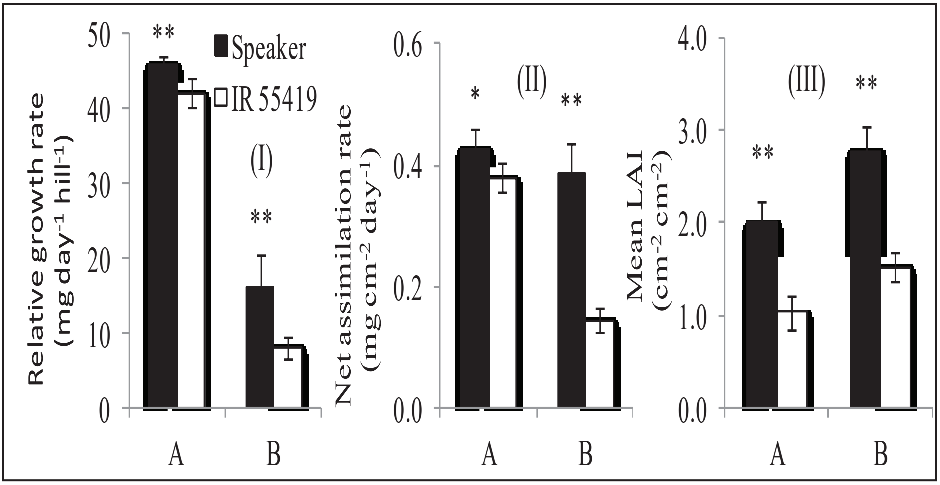


* indicates significant difference at 5% level of probability by *t*-test.
** indicates significant difference at 1% level of probability by *t*-test.

Figure 2. Changes in shoot dry weight (I), root dry weight (II) and root to shoot ratio (III) of pot- grown traditional (Speaker) and improved (IR 55419) upland rice varieties in 2012. A - approximately one month after emergence; B - approximately two months after emergence; C - heading; and D - approximately two weeks after heading.

Comparison of relative growth rate (RGR) and analysis of RGR

To further investigate the differences in dry matter accumulation, the relative growth rate (RGR), net assimilation rate (NAR) and leaf area index (LAI) before heading, as well as after heading were compared among the selected upland rice varieties. The relative growth rate in 'Speaker' was significantly higher before and after heading than in IR 55419 (Figure 3-I). The higher relative growth rate in 'Speaker' was supported by the higher net assimilation rate (Figure 3-II) and larger leaf area (Figure 3-III) before and after heading than in IR 55419. It has been reported that the higher crop growth rate after heading in high-yielding indica rice variety accumulated higher dry matter (Taylaran et al., 2009). The higher relative growth rate, particularly after heading, might also be responsible for the higher dry matter production in 'Speaker'.



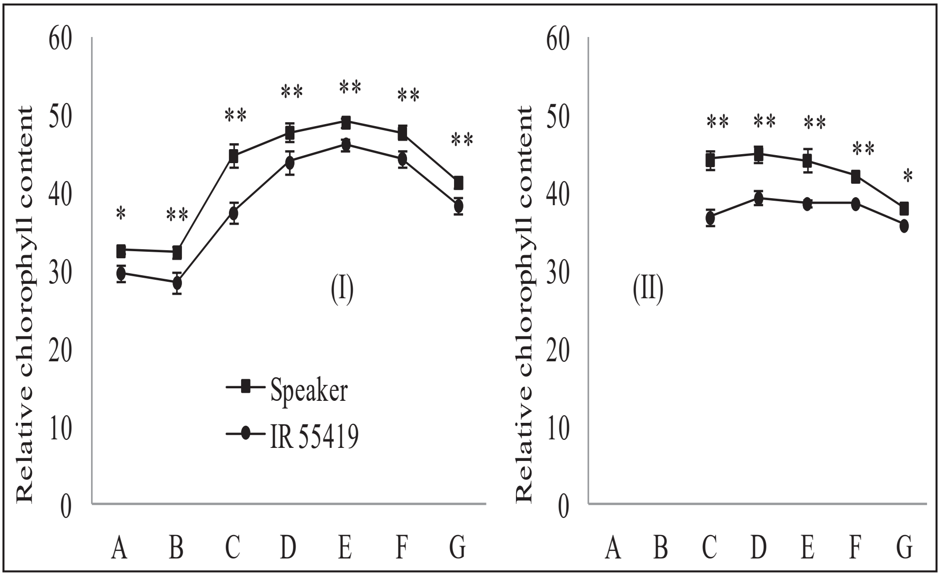
* indicates significant difference at 5% level of probability by *t*-test.
** indicates significant difference at 1% level of probability by *t*-test.

Figure 3. Relative growth rate (I), net assimilation rate (II) and mean leaf area index (III) from one month after emergence to heading (A) and from heading to two weeks after heading (B) of traditional (Speaker) and improved (IR 55419) upland rice varieties.

Relative chlorophyll dynamics of selected upland rice

The SPAD values or relative chlorophyll content reading can be used to monitor the agronomic efficiency of nitrogen fertilizer of rice plant (Peng et al., 1996; Hussain et al., 2000; Yang et al., 2014). The high-yielding traditional upland rice 'Speaker' maintained significantly higher relative chlorophyll content of the leaves throughout the growth period (Figure 4). The maintenance of higher chlorophyll content could lead to higher yield and dry matter production

(Ramesh et al., 2002; Taylaran et al., 2009; Hirasawa et al., 2010). The strong linear relationship between SPAD values and leaf nitrogen concentration and between leaf nitrogen and the rate of leaf photosynthesis has been reported leading to higher dry matter production (Hirasawa et al., 2010). These results suggest that the maintenance of higher relative chlorophyll content might also be attributed to the higher dry matter production in 'Speaker'.



* indicates significant difference at 5% level of probability by *t*-test.
** indicates significant difference at 1% level of probability by *t*-test.

Figure 4. Relative chlorophyll content (SPAD value) of upper fully expanded and flag leaf (I) and third leaf (II) of pot-grown traditional (Speaker) and improved (IR 55419) upland rice varieties in 2012. The letters A to G indicate growth stages: A - one month after emergence; B - two months after emergence; C - booting stage; D - heading stage; E - one week after heading; F - two weeks after heading; G - three weeks after heading, respectively.

Conclusion and Recommendation

The traditional upland rice ‘Speaker’ produced comparably higher yield with that of improved upland rice variety IR 55419 outperforming the check variety Ri-5 and two other traditional upland rice varieties, ‘Dinorado’ and ‘Cabuyoc’, respectively. The yields of ‘Speaker’ and IR 55419 were consistently higher even when subjected to drought induction. The higher dry matter production in ‘Speaker’ was attributed to the higher dry matter accumulation before and after heading. The claim was supported by the maintenance of larger root system before and after heading than in IR 55419. ‘Speaker’ maintained higher relative chlorophyll content (SPAD value) throughout the growth period. Moreover, the relative growth rate was significantly higher before and after heading in ‘Speaker’, which was supported by the higher net assimilation rate and larger leaf area than in IR 55419, suggesting the higher photosynthetic efficiency of ‘Speaker’. The mechanisms underlying the higher photosynthetic efficiency and nutrient uptake capacity might be considered in the future research under drought condition to characterize further the potential of traditional upland rice ‘Speaker’ for drought adaption in marginal uplands.

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