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Drought tolerance, phosphorus efficiency and yield characters of upland rice lines

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Abstract

Objective of this study was to evaluate the characters of drought tolerance, P efficiency and yield of some upland rice lines based on shoot biomass, P accumulation and grain yield. Nine lines of upland rice [viz. aromatic upland rice (Unsoed: G9, G13, G19, G35, G39), upland rice from Rice Research Center Sukamandi (IR-80340-23-B-B-1-B-B, IR 75885-25-1-3-B-5-1-2-B-B, IR 75885-26-2-3-B-18-B-2-1-B), upland rice from University of Mataram (Unram 1E)], four P doses per pot [viz. 0, 0.20, 0.40 and 0.55 kg P2O5] and soil water availability [viz. field capacity (FC) (-10 kPa), 50% FC (-24 kPa), 75% FC (-17 kPa) and 25% FC (-30 kPa) were tested. The study was arranged in randomized complete block design with three replicates. The result showed that upland rice lines of IR 75885-26-2-3-B-18-B-2-1-B, Unsoed G9 and Unsoed G19 resulted higher in grain yield under drought condition than others. Yet, Unram 1E and Unsoed G13 had potency to drought even low in grain yield. Meanwhile, upland rice lines of IR 75885-25-1-3-B-5-1-2-B-B, IR 75885-26-2-3-B-18-B-2-1-B and Unsoed G19 resulted higher in grain yield under low dose of P than others. Unsoed G9 had both characters in efficient and respond to P, and drought tolerance with high in grain yield. Therefore, it needs to evaluate the performance consistency of both characters on those lines through grown under real conditions in the field of rainfed areas.

Key words: Drought tolerance, P efficiency, Upland rice lines, Grain yield

Introduction

Drought is a major limitation to the productivity of agricultural systems and food production worldwide. Among cereal crops that are the major carbohydrate staples for humans, even intermittent water stress at critical stages may result in considerable yield reduction and crop failure. The current environmental problems caused by the sustainability of water consumption have become priority research areas especially in rainfed area where the rainfall is the main source of water or plant growth. The lack of water is also threatening the sustainable production of rice especially in Asia where rice is the most important cereal crop (Bouman and Tuong, 2001). Due to erratic rainfall, drought stress is a serious limiting factor to achieve rice production stability, and a major problem to yield. Drought effect differs according to varieties, growth stage, level and duration to drought stress (Kato, 2004). Drought effect may have different impacts on reducing yield (Forbes and Watson, 1994; Lafitte et al., 2007) and declining rice production generally (Bouman et al., 2005) due to decreasing in growth and photosynthetic rate (Siddique et al., 1999; Zlatev and Lidon, 2012),

Upland rice plays an important role in bringing cleared areas into cultivation by finding characters of tolerance to acid, aluminium-toxic soils (Pinheiro et al., 2006). The problems of acid soils are complex even the major growth-limiting factor for upland rice differs depending on the degree of soil acidity. Phosphorus (P) deficiency is a major abiotic stress that limits rice productivity, particularly under upland conditions in acid soils such as ultisol and alfisol (Kirk et al., 1998). Dobermann et al. (1998) estimated that more than 90% of added fertilizer P may be rapidly transformed to P forms that are not easily available to plants.

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Under conditions of drought due to erratic rainfall and acid soils in which accumulation of toxic element such as Al, Mn and Fe with low of P availability arise and directly impairment the growth of crops so the proper management is a must to improve productivity of upland rice. Erratic rainfall and low soil nutrition of P are specific problems and as the main factor of food production in rainfed dry land area and it has a high risk on production (Fageria and Baligar, 1997; Amberger, 2000).

Rice as a staple food in Indonesia is the first priority to obtain national demand of food and it's mentioned in strategic planning of Indonesian Agricultural Research and Development Agency 2010-2014 due to it has not been met national demand yet. Expansive area of rice production in Indonesia to upland land areas is one alternative to keep and support national food security. Large potency of upland areas could be possible to support upland rice production and enhance contribution to national rice production (Center of Research and Development, 2008).

Selected variety could be possible adaptable grown under specific constraints of limited water and low P availabilities to enhance production. Moreover, those varieties might have the characters of drought tolerance, P efficient and high yield. This is an option and one solution to improve upland rice production to meet national production demand. Several studies were done regarding to P performance in plant (Fageria et al., 1988; Wissuwa, 2003; Akinrinde and Gaizer, 2006; Li et al., 2009), and plant performance under drought condition (Hirayama et al., 2006; Venuprasad et al., 2007; Liu et al., 2007; Lasalita-Zapico et al., 2008). However, study on selection of genotypes with both characters of drought tolerance and P efficient to improve yield has been limited conduct.

Developing rice varieties under acid-soil (low P availability) and drought tolerances (erratic rainfall) would be a way to introduce upland rice in upland cropping systems area as one main objective. The large areas of upland with the some constraints are the potency to develop with emphasis on upland rice production as a main staple food. Therefore, finding out of genotypes of upland rice with the characters of drought tolerance, P efficient and high yield must be done to get the suitable genotypes in specific upland areas.

Materials and Methods

The studies were carried out at Agronomy and Horticulture laboratory and screen house of Faculty of Agriculture Jenderal Soedirman University in July – December 2010. In first study, drought tolerance selection methods were tested by seed germinated level (at laboratory) and seedling level (at screen house), and P efficiency selection was done in screen house on young plant (30 days after sowing) (Ahadiyat et al., 2012). Then, the pot study in screen house was done to evaluate the potency of drought and P efficiency lines of upland rice from previous study.

Upland rice lines of aromatic upland rice (Unsoed: G9, G13, G19, G35, G39), upland rice from Rice Research Center Sukamandi (IR-80340-23-B-B-1-B-B, IR 75885-25-1-3-B-5-1-2-B-B, IR 75885-26-2-3-B-18-B-2-1-B), and upland rice lines from University of Mataram (Unram 1E) in first study were used as materials (Ahadiyat et al., 2012).

This further study was evaluated the potency of drought tolerance and P efficiency by characterization on shoot biomass, P accumulation and grain yield. Three seeds were dibbled in pot (8.5 kg dried soil) and it will be left two plants per pot after 14 days after sowing. The experimental treatments were composed of combinations of nine lines of upland rice [viz. aromatic upland rice (Unsoed: G9, G13, G19, G35, G39), upland rice from Rice Research Center Sukamandi (IR-80340-23-B-B-1-B-B, IR 75885-25-1-3-B-5-1-2-B-B, IR 75885-26-2-3-B-18-B-2-1-B), upland rice lines from University of Mataram (Unram 1E)], four P doses per pot [viz. 0, 0.20, 0.40 and 0.55 g P_2O_5] and soil water availability [viz. field capacity (FC) (-10 kPa), 50% FC (-24 kPa), 75% FC (-17 kPa) and 25% FC (-30 kPa). The study was arranged in randomized complete block design with three replicates.

Each pot received N at dose of 0.40 g and applied at 15 and 30 days after sowing each and K at dose of 0.20 g at 15 days after sowing using urea (46% N) and muriate of potash (50% K_2O), respectively. Super phosphate (18% P_2O_5) was applied following the treatments. The seedlings were thinned out to two plants per hill at 14 days after sowing. There was neither any pest nor diseases also weeds were controlled as need arise.

Dry weight of shoot biomass and grain yield was observed. Grain yield were gathered randomly from two pots as sample from each treatments and replication. Grain per pot was weighed as indicated of yield. Characterization of P efficiencies was calculated in use and absorption as reported by Fageria and Baligar (1997) and Fageria and Santos (2002).

All data were analyzed by using Analysis of Variance procedure (Steel and Torrie 1980) by using IRRIStat Software (2004). Treatment means were compared using Fisher's Protected LSD method.

Results

Characterization of upland rice lines on drought tolerance

Characteristics of upland rice lines under drought condition resulted in the variation on shoot biomass and grain yield (Table 1). Response of upland rice lines to express adaptability under drought condition could indicate the level of drought tolerance. Drought tolerance is a function of morphological characters i.e. plant biomass and stability of yield. This study showed that shoot biomass declined along with reducing soil water content (Figure 1). Growth of shoot part stunted enough under soil water condition of -30 kPa on upland rice lines of IR-75885-25-1-3-B-5-1-2-B-B, IR-75885-26-2-3-B-18-B-2-1-B, Unsoed G13, G19 and Unram 1E upland rice lines with shoot biomass of less than 20 g.

Grain yield of more than 8 t/ha gained under favorable condition (-10 kPa) on upland rice lines of IR-75885-25-1-3-B-5-1-2-B-B, IR-75885-26-2-3-B-18-B-2-1-B, Unsoed G19 and G9 (Figure 2). However, the grain yield under drought condition (-30 kPa) on almost all upland rice lines gained not more than 4 t/ha. Eventhough, in the same condition some upland rice lines gained grain yield more than 4 t/ha such as IR-75885-26-2-3-B-18-B-2-1-B, Unsoed G19 and G9 (Figure 2). Comparison between stress (-30 kPa) to optimum (-10 kPa) conditions on grain yield showed that some upland rice lines gained more than 75 percent i.e. Unram 1E and Unsoed G13 (Figure 3). This indicated that both upland rice lines still had capacity to produce high grain even under stress condition about 75 percent compared to the yield under optimum condition.

Table 1. Analysis of variance of effect upland rice lines and soil water availability on shoot biomass, P tissue content, P use efficiency (PUE) and grain yield.

Parameter	Upland rice Line (G)	Soil water availability (W)	P dose (P)	G x W	G x P	W x P	G x W x P
Shoot Biomass	**	**	**	*	ns	ns	ns
P tissue content	**	**	**	**	**	**	**
PUE	**	**	**	**	ns	ns	ns
Grain yield	**	**	**	**	ns	ns	ns

ns-non significant, * P<0.05,** P <0.01

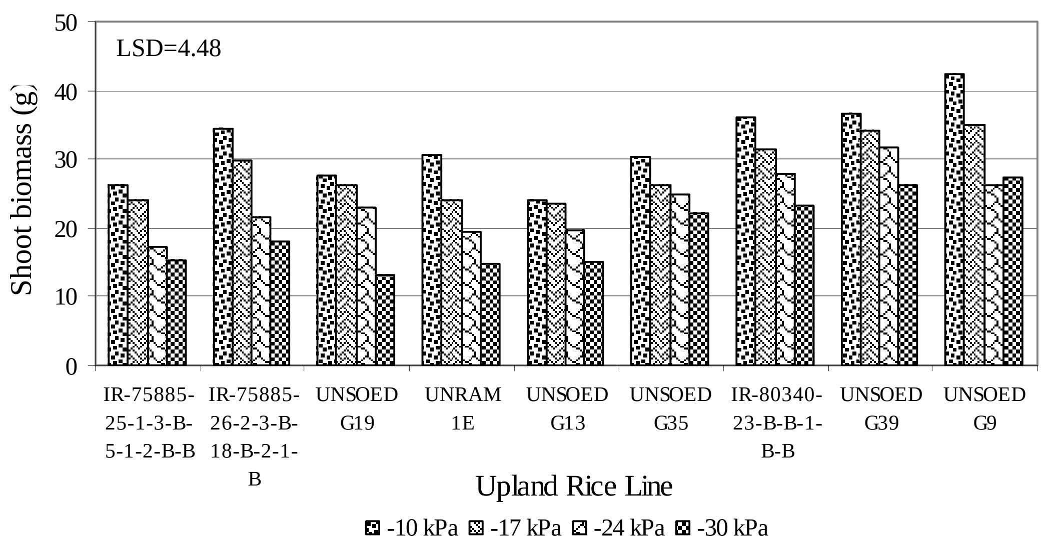

Figure 1. Shoot biomass of upland rice lines at different water availability.

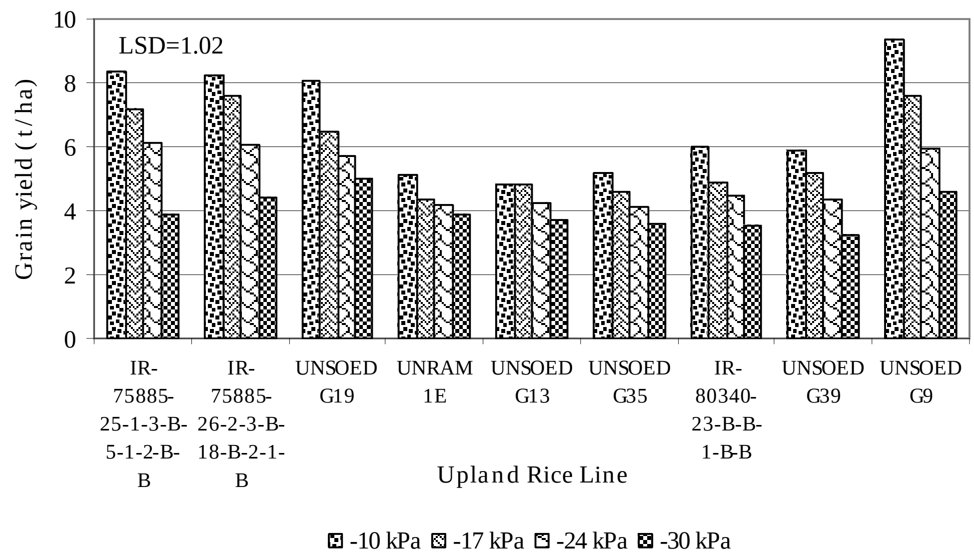

Figure 2. Grain yield of upland rice lines at different water availability.

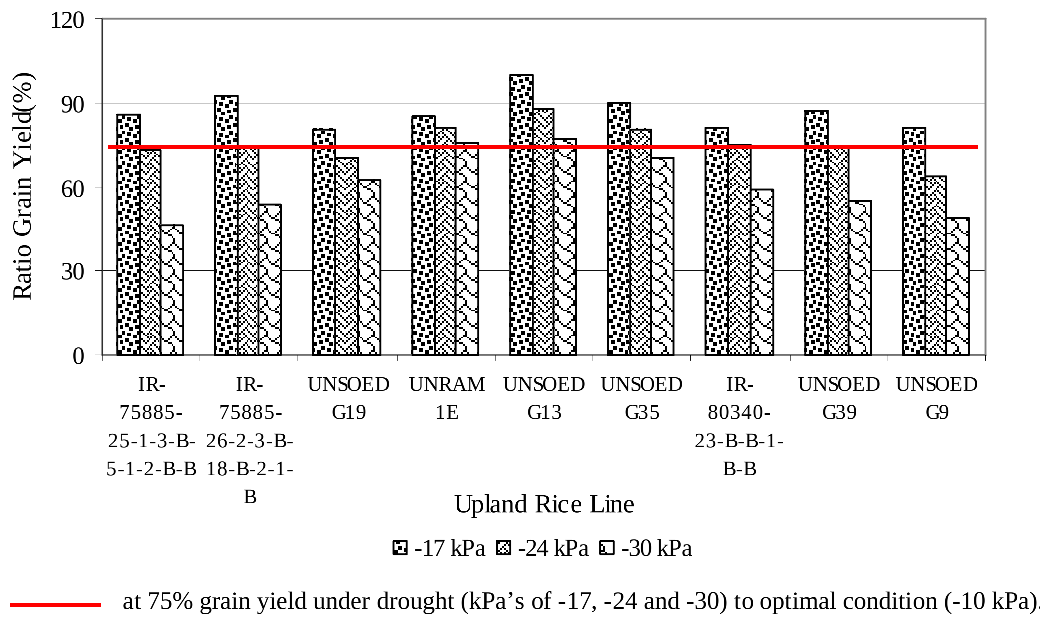

Figure 3. Grain yield ratio of upland rice lines at different water availability.

Characterization of upland rice lines on P efficiency

Characteristics of upland rice lines under different P doses resulted in variation of shoot biomass, P tissue content, P Use Efficiency and grain yield (Table 1). Generally, shoot biomass and P tissue content increased along with increased of P application. Low dose of P (45 kg/ha P_2O_5) obtained more than 25 g of shoot biomass on upland rice lines of IR-75885-26-2-3-B-18-B-2-1-B, IR-80340-23-B-B-1-B-B, Unsoed G9 and Unsoed G39. For high dose of P (90-135 kg/ha P_2O_5) obtained shoot biomass of more than 30 g i.e. upland rice lines of IR-80340-23-B-B-1-B-B, Unsoed G9 and Unsoed G39. Yet, consistency result in application of low to high dose of P (45-135 kg/ha P_2O_5) resulted in high shoot biomass of more than 30 g gained by upland rice lines of Unsoed G9 and Unsoed G39 (Figure 4).

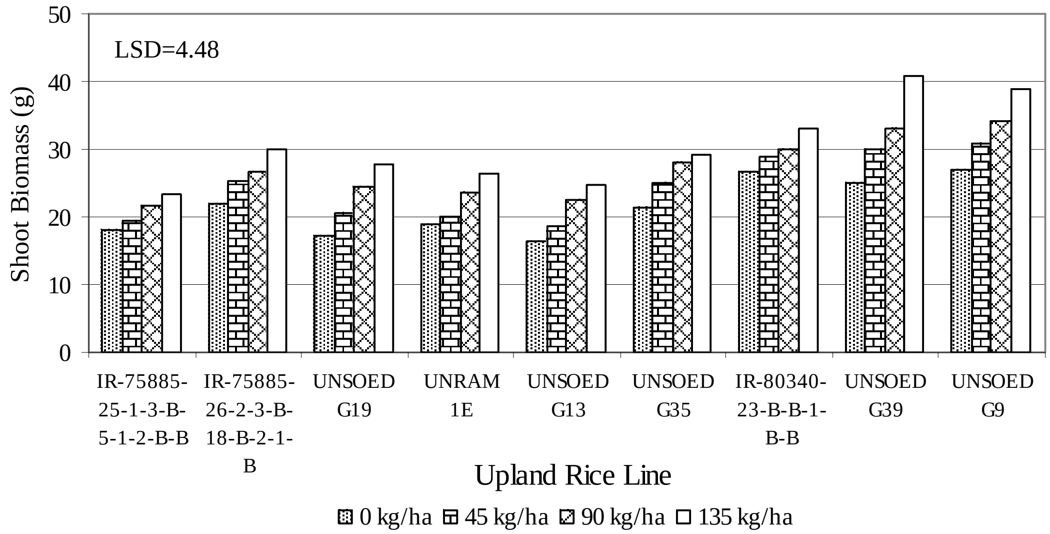

Figure 4. Shoot biomass of upland rice lines at different P doses.

Different upland rice lines had varied responses on P tissue content. Generally, application of P dose of 45-90 kg/ha P_2O_5 accumulated P tissue content between 200 - 300 mg/g. Only upland rice lines of Unram 1E and Unsoed G35 accumulated P tissue content more than 300 mg/g with applied of 135 kg/ha P_2O_5 (Figure 5).

There was contradiction in Absorption Efficiency of P compared to shoot biomass and P tissue content. Increasing dose of P resulted declining of efficiency level. All lines gained level of P efficiency more than 20 mg/mg with dose of P 45 kg P_2O_5/ha. Application dose of P above 45 kg P_2O_5/ha resulted the declining of P efficiency (Fig. 6). Upland rice lines of IR-80340-23-B-B-1-B-B, Unsoed G9 and G39 gained P use efficiency above 120 mg/mg but others gained below 120 mg/mg (Figure 8).

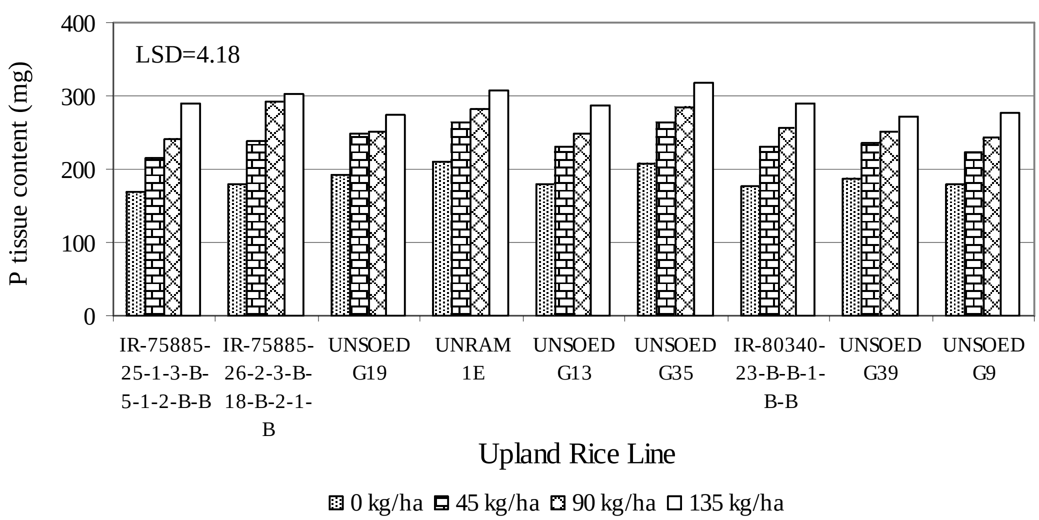

Figure 5. P tissue content of upland rice lines at different P doses.

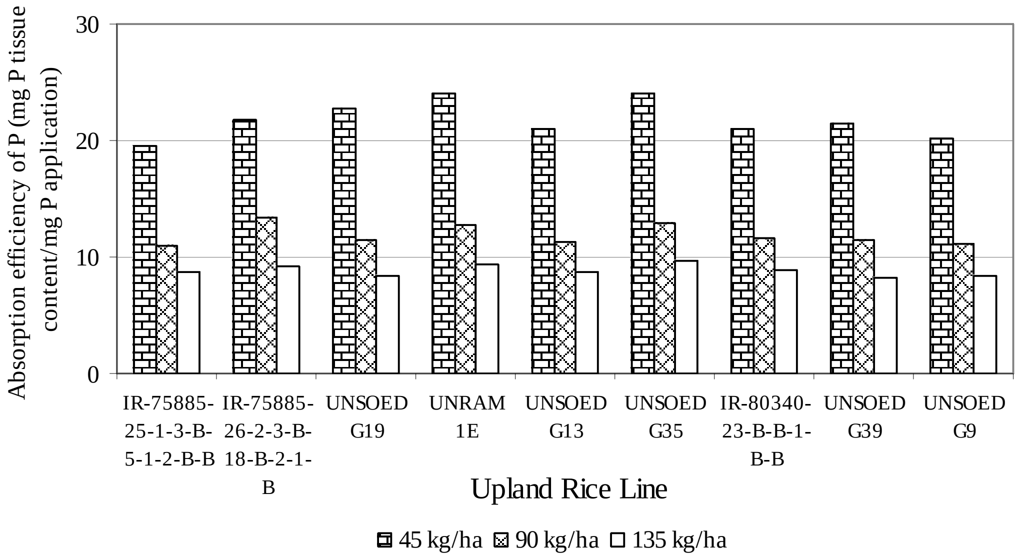

Figure 6. Absorption efficiency of P of upland rice lines.

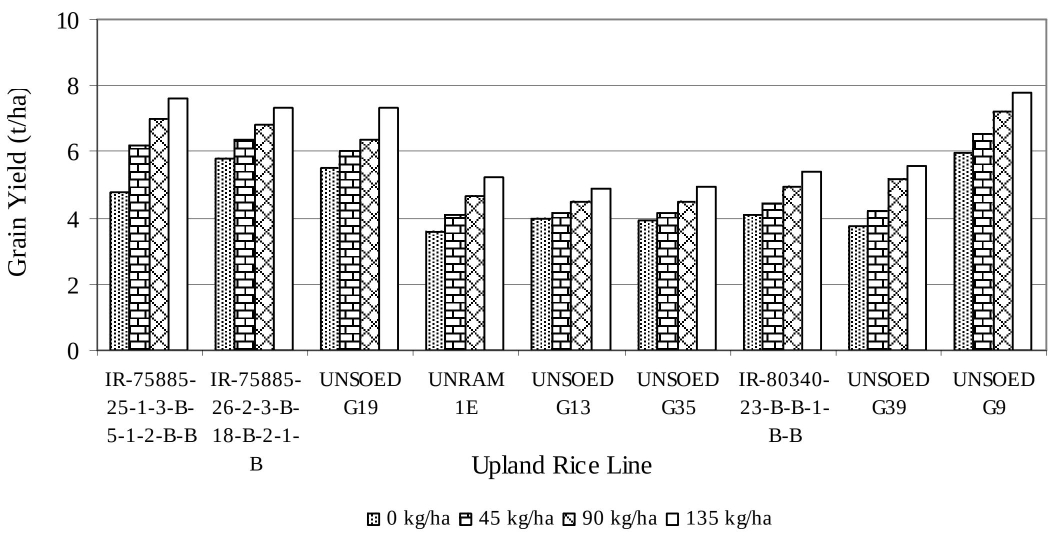

Figure 7. Grain yield of upland rice lines at different P doses.

Grain yield of IR-75885-25-1-3-B-5-1-2-B-B, IR-75885-26-2-3-B-18-B-2-1-B, Unsoed G19, and Unsoed G9 lines had the higher result compared to others under different application of P. In general, all upland rice lines as mentioned above had grain yield potency more than 6 t/ha but others gained less than 4.5 t/ha (Figure 7).

Grouping was arranged to separate different characters of upland rice lines based on P use efficiency and shoot biomass viz. efficient and responsive, efficient but not responsive, not efficient but responsive and either not efficient or responsive (Figure 8). Categorized of upland rice lines as distributed by IR-80340-23-B-B-1-B-B, Unsoed G9 and G39 were efficient and responsive, IR-75885-26-2-3-B-18-B-2-1-B and Unsoed G35 were efficient but not responsive, and others were either not efficient or responsive. There no upland rice lines had character of not efficient but responsive (Figure 8).

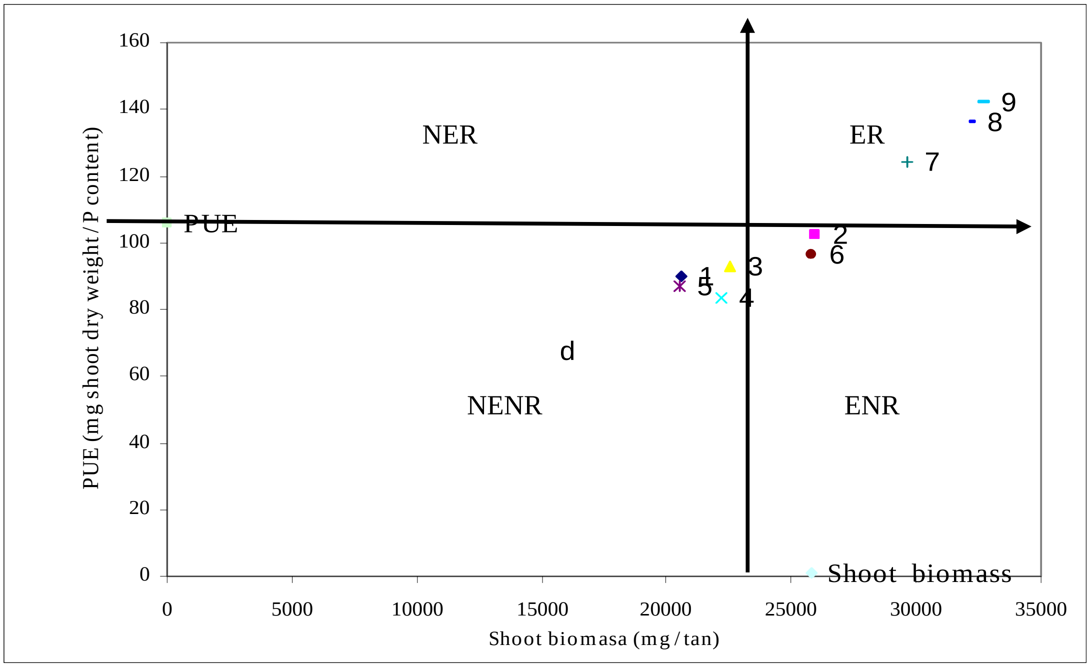

Figure 8. Grouping upland rice lines based on character of efficiency and responses on P use.

PUE = P use efficiency; ER = Efficient and Responsive; NER = Non Efficient and Responsive; ENR = Efficient and Non Responsive; NENR = Non Efficient and Non Responsive.

1. IR-75885-25-1-3-B-5-1-2-B-B	6. UNSOED G35
2. IR-75885-26-2-3-B-18-B-2-1-B	7. IR-80340-23-B-B-1-B-B
3. UNSOED G19	8. UNSOED G39
4. UNRAM 1E	9. UNSOED G9
5. UNSOED G13	

Discussion

The variation of results on drought tolerance was evidence that each upland rice lines had different response. Matsuo et al. (2009) reported that morphological characters such as shoot weight tend vary among different conditions. The genotypes may respond different to some factor i.e. age and maturity, biochemical compositions and genetic variability of seeds (Ahmad et al., 2009). The nature of the trade-off between drought tolerance and plant growth rate also constrains the selection for optimal drought-adapted genotypes. The aspects of plant–environment interactions should be considered before establishing selection programs for drought adaptation. Selecting for early maturation also results in selection for drought-stress avoidance (Juliano et al., 2007). Genotypes adapted to particular conditions usually perform poorly when these conditions are absent. Therefore it is expected that the adoption of a single drought-adaptation strategy will not be adequate for all environments (Porporato et al., 2001; Tardieu, 2005; Juliano et al., 2007).

This study was carried out to find out the potential lines with the given typeset and it will be suitable grown under dry land areas especially in rainfed condition. Thus, under rainfed systems, the problems arise from the variability of water regimes, so the soils may drain and re-flood at least once during the season. The resulting water stress is often compounded by nutrient deficiencies especially of P because the soils are often inherently low in P and solubility (Haefele et al., 2006). Identification of rice genotypes in lowland and upland has been done on P efficiency and the differences occur on the ability to capture soil P and utilize it in biomass production as long as the other factors are not limited (Ismail et al., 2007).

Therefore, differences in ability of genotypes of particular species to grow on low P soils can results from quite different phenomena. Some crops grow well on a high or low P soils i.e. potatoes

(Sattelmacher et al., 1991) and *B. oleraceae* (Greenwood et al., 2005). But, commonly dry land areas especially rainfed has a characteristic of nutrient deficiencies, particularly of P (Ozturk et al., 2005) and give adverse effect on rice production (Huguenin-Elie et al., 2009). So, selection of upland rice varieties that grows well on soils with low levels of plant available P is needed to improve productivity.

Selection of P efficiency genotypes refers to Fageria and Baligar (1997) and Fageria and Santor (2002) by which mentioned that biomass weight and P tissue content on shoot part are suitable to use for P efficiency genotypes selection. Other studies of rice were done on P efficient (Ozturk et al., 2005; Gunes et al., 2006) based on ratio of biomass weight between deficient to sufficient conditions. Even though, the results showed the variation under both methods of shoot biomass and P tissue content but some upland rice lines gained the consistent results on shoot biomass and P use efficiency characters such as Unsoed G9 and Unsoed G39. This is the fact that to identify useful traits into broadly adapted genotypes, it is important to understand the mechanisms involved and their genetic basis (Huguenin-Elie et al., 2009) and genotypes develop diverse adaptive responses when they suffer from P deficiency stress (Ozturk et al., 2005).

In general, upland rice lines with the character of tolerance to drought tend low in P efficiency and vise versa. However, Unsoed G9 showed to be superior in drought tolerance and P efficiency. Improving in morphological and physiological characters of plant could enhance level of drought tolerance but not for yield. Previously studies on five upland varieties showed that low in leaf areas and number of panicles gained the low yield (Ahadiyat dan Harjoso, 2010a,b). This is a fact that paddy is sensitive plant to water deficit and would be resulted drought effect and could gain the low in growth and yield.

However, drought character is the important thing for paddy under dry land area especially in rainfed areas with character of low water availability due to low intensity of rainfall during plant growth. Therefore, some genotypes with the character of drought tolerance could be used as important genetic resources for parental and could be possible to breed with genotypes with the character of high yield even low tolerance to drought. Thus, additional character for improving adaptability under acid soils must be found. The characters as mentioned above could be possible to further breed with genotypes characters of P efficient. This effort must be done because of high in P performance of content and efficient resulted low in yield as reported by Ozturk et al. (2005) and Gunes et al. (2006).

Some upland rice lines with the characters of efficient but not respond and not efficient and not respond had high performance in yield potency (>6 t/ha), dry biomass of shoot and root. It could develop by using both characters as genetic resources for adaptable genotypes grown under acid soils (low P availability). As mentioned by Fageria et al. (1988), Fageria and Baligar (1997) and Gunes et al. (2006) that selection of genotypes under low P availability in soils could use dry weight of shoot and root as indicators.

Under control condition in screen house, this study has been found the potential lines with characters of drought tolerance and P use efficiency. Therefore, it needs the further studies to ensure the performance consistency of all upland rice lines through grown in real field conditions of rainfed areas. To achieve the better inform of crop improvement, research must continue and understanding the interactions between plant genotypes and the growing environment under conditions of P deficient (Wissuwa, 2003) and drought (Parry et al., 2005).

Conclusion

Upland rice lines of IR 75885-26-2-3-B-18-B-2-1-B, Unsoed G9 and Unsoed G19 gained higher in grain yield under drought condition than others. Yet, Unram 1E and Unsoed G13 had potency to drought even low in grain yield. For P efficiency characterization, upland rice lines of IR 75885-25-1-3-B-5-1-2-B-B, IR 75885-26-2-3-B-18-B-2-1-B and Unsoed G19 gained in higher grain yield under low dose of P than others along with characters of not responsive and, efficient or not efficient to P. Upland rice line of Unsoed G9 had characters in drought tolerance and P efficiency with high in grain yield. Therefore, for obtaining ideotype variety with the characters of drought tolerance, P efficient and high yield is needed to conduct the further studies and evaluate the performance consistency of upland rice lines through grown under real conditions in the field of rainfed areas for ensure the potency of each lines.

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