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Selection of upland rice genotypes on drought tolerance and P efficiency at laboratory and screen house levels

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Objective of this study was to evaluate some upland rice genotypes on drought tolerance and P efficiency at laboratory and screen house level. PEG (Polyethylene glycol) 6000 as seedling growth medium and young plant in pot at limited water for drought tolerance, and on young plant under application of 20 ppm (deficient) and 80 ppm (sufficient) of P solution in pot for P efficiency were tested. The result showed that some genotypes obtained the potency of drought tolerance i.e. Unsoed G-19, B-126-44F-MR-2, IR-75885-25-1-3-B-5-1-2-B-B and Unsoed G-39. P efficient genotypes obtained by Unsoed G9, UNRAM 9E, Unsoed G10 and Unsoed G39. In general, the high ratio in drought tolerance followed by the low ratio in P efficiency characters and vise versa. However, Unsoed G39 gained the high ratios on drought tolerance and P efficiency.

Key words: upland rice genotypes, drought tolerance, P efficiency

Introduction

Generally, upland areas have typically led to various degrees of soil acidity because of deep weathering and leaching cations. 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.

Meanwhile, erratic rainfall condition is also happen in upland areas where inadequate water at one growth stage or another limits yield. Drought stress is a

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serious limiting factor to gain stability of rice production. The effect of drought varies with the variety, degree and duration of stress and its coincidence with different growth stages (Kato, 2004). The full yield potential of rice on any site in any season is probably never realized. Periods of unsuitable weather causes drought hence reduce the yield (Forbes and Watson, 1994). It is estimated that 50% of the world rice production is affected more or less by drought (Bouman *et al*., 2005).

It is necessary to manage upland areas with the characters of soil acidity and related to soil constraints such as drought condition due to erratic of rainfall to increase the productivity of upland rice. Therefore, in strategic planning of Indonesian Agricultural Research and Development Agency 2010-2014 mentioned that rice is the first priority to gather national demand of food. However, currently the level of national rice production has not been met national demand yet. Area of rice production in Indonesia is dominantly under irrigated so it needs to expand to upland land areas as one alternative to keep and support national food security. Potency of upland areas is still large and it has a capacity to develop optimal food crop production especially for upland rice. In present, upland rice production contributes about 5-6% only to national rice production (Center of Research and Development, 2008). Erratic rainfall is the main factor that food production in rainfed dry land area and it has a high risk on production. Thus, the area has specific problems on low soil nutrition especially P and acid soil condition (Fageria and Baligar, 1997; Amberger, 2000).

Growing appropriate variety could enhance production. Therefore, selection of variety in selected area is an important thing to gain the adaptable one. Finding the new genotypes that suitable for upland area with specific constraint is needed to study by selection upland rice genotypes with the characters of drought tolerance, P efficient and high yield. This is one solution in order to improve rice production in upland area under limited water and acid conditions.

Some studies were done to select and improve upland rice production i.e. selection of some cultivars on P use efficiency (Fageria *et al*., 1988), P uptake under low P in soil of rice and root systems (Wissuwa, 2003), performance and P uptake of different tropical rice varieties (Akinrinde and Gaizer, 2006), leaf temperature as indication of drought tolerance (Hirayama *et al*., 2006), selection for grain yield under drought condition (Venuprasad *et al*., 2007), Panicle water potential and leaf water potential were measured as drought treat indication (Liu *et al*., 2007), selection of drought tolerance of rice based on morphological characters (Lasalita-Zapico *et al*., 2008), P uptake under Fe-P solution (Li *et al*., 2009). However, study on selection of genotypes with both characters of drought tolerance and P efficient has been limited conduct.

To develop rice varieties with high yield potential, acid-soil and drought tolerances for the purpose of introducing upland rice in upland cropping systems area was one main objective. Therefore, this study was important to conduct as an alternative solution to find out the genotypes of upland rice with the characters of drought tolerance, P efficient and high yield, and suitable in specific upland areas.

Materials and methods

The studies were carried out at Agronomy and Horticulture laboratory and screen house of Faculty of Agriculture Unsoed in April to June 2010. Genotypes drought tolerance selection methods were tested by seed germinated level in laboratory and seedling level in screen-house and P efficiency selection was done in screen-house on young plants (30 days after sowing).

Genotypes of Aromatic upland rice (Unsoed: G9, G10, G12, G13, G19, G34, G35, G39, G136), upland rice from Rice Research Center Sukamandi (B-126-44F-MR-2, B-124-98C-MR-1, IR 80340-23-B-B-1-B-B, IR 77379-33-3-7-19-1-B, IR 75885-25-1-3-B-5-1-2-B-B, IR 75885-26-2-3-B-18-B-2-1-B), Unram genotypes (UNRAM 1E, 4E, 9E, 17E) and variety control (Situpatenggang) were used as materials.

Selection of genotypes on drought tolerance

First, solution of 0, 10, 20 % PEG (Polyethylene glycol) 6000 were used in drought tolerance evaluation at seed germinated level (Lasalita-Zapico *et al.*, 2008). Seeds were sowed in sand medium during seven days and then replaced to medium of PEG solution in Petridis by number of 20 seedlings each. Complete Randomized Design with three times replication was applied to evaluate the responses of seedling under stress condition of PEG solution and observed for 48 hours. Finally, Fresh seedling in each petridish was collected and weighed.

Second, evaluation on drought tolerance was carried out in pot at screen house by Complete Randomized Design with three times replication. Two treatments were applied i.e. watering for four and ten days and then ceased. Three seeds were dibbled and retained two seedlings for evaluation. Water is applied after seeds germinated in four days after sowing. Evaluation was done on dry weight of seedling at harvest time (14 days) from each treatment (IRRI, 2002). Dry weight of seedling was determined after drying at 80 ^{0}C.

Data in both evaluations were analyzed by calculating ratio of under stress conditions to favorable conditions as indication of the tolerance level in each genotype. Only, the average of different stress conditions of PEG solution (P10/P0 and P20/P0) was calculated.

Selection of genotypes on P efficiency

Fifteen seeds were dibbled in pot (1.5 kg) at screen house. At seven days after sowing, good ten seedlings were kept for further evaluation. Application of nutrition was applied at onset of sowing date. According to Gunes *et al,* (2006), N was applied at dose 200 mg/kg $Ca(NO_3)_2.4H_2O$ (0.3 g/pot) and K at dose 50 mg/kg KNO_3 (0.075 g/pot) in each pot. P was applied based on treatments at deficient dose of 20 mg/kg (0.03 g/pot) and sufficient dose of 80 mg/kg (0.12 g/pot).

Observation was done up to 30 days and was evaluated on shoot dry weight and P content. Dry shoot weights were determined after drying at 80 ^{0}C. P content was determined at harvested time (30 days old) of shoot, dried at 70 ^{0}C, ground and ashed at 550 ^{0}C for determination of P concentration in the whole shoot. The ashed samples were then dissolved in 3.3% HCl and analyzed for P by using the method of Barton (1948).

Data were analyzed by calculating ratio of under deficient condition to sufficient condition as indication of the P efficience level (relative shoot growth) in each genotype (Ozturk *et al*., 2005).

Results and discussions

Selection of genotypes on drought tolerance

There has a variation on ratio of index drought tolerance among genotypes under 10% and 20% PEG solutions. These values gave indication that each genotype showed the different responses on drought conditions as the result of tolerance level.

Based on PEG test showed that Situ Patenggang variety as a control gained the high ratio of drought tolerance of 93.83% (10% PEG) and 77.78% (20% PEG) compared to average of overall genotypes value (Table 1). Selected genotypes for drought tolerance were taken by the high ratio more than overall average values of 81.66% (PEG 10%) and 72.22% (20%). Some genotypes had drought tolerance index >81.66% under 10% PEG i.e. B-126-44F-MR-2 (83.59%), UNRAM 17E (86.90%), Unsoed G-39 (87.20%), UNRAM 9E (90.43%), UNRAM 4E (90.60%), Unsoed G-35 (92.75%), Unsoed G-136 (95.04%), Unsoed G-19 (95.37%) and IR-75885-25-1-3-B-5-1-2-B-B (95.59%) (Table 1) and drought tolerance index >75% under 20% PEG i.e. Unsoed G-39 (77.95%), UNRAM 4E (78.21%), Unsoed G13 (78.81%), Unsoed G35

(84.25%), Unsoed G-136 (86.91%), Unsoed G-19 (88.33%), B-126-44F-MR-2 (88.78%) and IR-75885-25-1-3-B-5-1-2-B-B (97.71%) (Table 1).

Table 1. Fresh seedling weight (g) of upland rice genotypes under different concentration of PEG (Polyethylene glycol) 6000 on drought tolerance index

Genotype	PEG0	PEG10	PEG20	Drought tolerance index (%)	
				P10/P0	P20/P0
Situ Patenggang	0.0810	0.0760	0.0630	93.83	77.78
UNRAM 4E	0.1170	0.1060	0.0915	90.60	78.21
Unsoed G19	0.0986	0.0941	0.0871	95.37	88.33
B-126-44F-MR-2	0.1168	0.0976	0.1037	83.59	88.78
Unsoed G136	0.0779	0.0740	0.0677	95.04	86.91
UNRAM 17E	0.1375	0.1195	0.0760	86.90	55.27
B-124-98C-MR-1	0.1310	0.0950	0.0842	72.52	64.29
UNRAM 1E	0.1243	0.0933	0.0898	75.02	72.19
IR 80340-23-B-B-1-B-B	0.1189	0.0968	0.0684	81.44	57.57
IR 77379-33-3-7-19-1-B	0.1402	0.0939	0.0925	66.97	65.97
IR 75885-25-1-3-B-5-1-2-B-B	0.0895	0.0856	0.0875	95.59	97.71
IR 75885-26-2-3-B-18-B-2-1-B	0.1177	0.0950	0.0783	80.74	66.54
Unsoed G12	0.1333	0.0914	0.0863	68.53	64.71
Unsoed G13	0.1475	0.1164	0.1163	78.92	78.81
Unsoed G9	0.1278	0.0979	0.0853	76.61	66.77
Unsoed G34	0.1943	0.1090	0.1081	56.09	55.66
Unsoed G35	0.1111	0.1031	0.0936	92.75	84.25
UNRAM 9E	0.1117	0.1010	0.0755	90.43	67.60
Unsoed G10	0.1300	0.1003	0.0711	77.18	54.65
Unsoed G39	0.1026	0.0895	0.0800	87.20	77.95
Average				81.66	79.86

Remarks: PEG0 = 0% PEG; PEG10 = 10%; PEG; P20 = 20% PEG (percentage of PEG solution).

Based on pot test was resulted the vary drought tolerance index under different watering period. But, still Situ Patenggang variety showed the high index of 81.23%. Drought tolerance indices >70% as average value of overall genotypes were B-126-44F-MR-2 (70.08%), Unsoed G-13 (74.93%), B-126-44F-MR-2 (78.26%), Unsoed G-19 (80.91%), IR-75885-25-1-3-B-5-1-2-B-B (82.28%), IR-75885-26-2-3-B-18-B-2-1-B (85.40%), UNRAM 17E (95.88%) and Unsoed G-39 (94.00%) as potential genotypes for drought tolerance (Table 2).

The result form two different methods indicated vary and inconsistent in each genotypes. Therefore, selected genotypes were taken on genotypes with the consistent value of drought tolerance index in different method as mentioned above. Unsoed G-19, B-126-44F-MR-2, IR-75885-25-1-3-B-5-1-2-B-B and Unsoed G-39 showed the consistency values of drought tolerance index (Table 3).

Tabel 2. Dry biomass (g) of upland rice genotypes at 14 days under different period of watering on drought tolerance index

Genotype	WA-4	WA-10	Drought tolerance index (%)
Situ Patenggang	0.1255	0.1545	81.23
UNRAM 4E	0.0904	0.1593	56.78
Unsoed G19	0.0915	0.1131	80.91
B-126-44F-MR-2	0.0753	0.1075	70.08
Unsoed G136	0.0665	0.0978	68.03
UNRAM 17E	0.1395	0.1455	95.88
B-124-98C-MR-1	0.0450	0.0575	78.26
UNRAM 1E	0.0945	0.1900	49.74
IR 80340-23-B-B-1-B-B	0.0728	0.1310	55.60
IR 77379-33-3-7-19-1-B	0.0775	0.1455	53.26
IR 75885-25-1-3-B-5-1-2-B-B	0.1203	0.1463	82.28
IR 75885-26-2-3-B-18-B-2-1-B	0.0965	0.1130	85.40
Unsoed G12	0.0912	0.1538	59.32
Unsoed G13	0.0824	0.1099	74.93
Unsoed G9	0.0631	0.0974	64.80
Unsoed G34	0.0810	0.1366	59.28
Unsoed G35	0.0975	0.1427	68.31
UNRAM 9E	0.1216	0.2080	58.45
Unsoed G10	0.0927	0.1725	53.72
Unsoed G39	0.1058	0.1125	94.00
Average			69.51

Remarks: WA-4 = only during 4 days applied water and then ceased.
WA-10 = only during 10 days applied water and then ceased.

Table 3. Comparison of drought tolerance index (DTI) on upland rice genotypes between PEG and pot methods

Genotype	DTI-PEG	DTI-Pot
Situ Patenggang	85.80	81.23
UNRAM 4E	87.05	56.78
Unsoed G19	89.87	80.91
B-126-44F-MR-2	88.02	70.08
Unsoed G136	91.46	68.03
UNRAM 17E	77.71	95.88
B-124-98C-MR-1	75.47	78.26
UNRAM 1E	74.40	49.74
IR 80340-23-B-B-1-B-B	74.63	55.60
IR 77379-33-3-7-19-1-B	67.96	53.26
IR 75885-25-1-3-B-5-1-2-B-B	94.78	82.28
IR 75885-26-2-3-B-18-B-2-1-B	78.25	85.40
Unsoed G12	67.68	59.32
Unsoed G13	82.99	74.93
Unsoed G9	76.54	64.80
Unsoed G34	58.98	59.28
Unsoed G35	91.66	68.31
UNRAM 9E	82.72	58.45
Unsoed G10	72.59	53.72
Unsoed G39	84.54	94.00

Remarks: DTI-PEG is obtained by calculating the average of DTI P10/P0 and P20/P0 in each genotype (Table 1); DTI-pot is obtained from Table 2.

The variation of result was evidence that each genotype had a different response on different test method. Otherwise, selected genotypes could be possible gotten by genotypes with the consistent values from different method. Both tests refer to Lasalita-Zapico *et al*. (2008) for PEG test and IRRI (2002) for pot test.

Selection of genotypes on P efficiency

Index of P efficiency based on shoot dry weight ranges from 57.67% (UNRAM 17E) to 94.31% (Unsoed G9) (Table 4). Situ Patenggang variety as a control had the highest P efficiency (99.29%). Efficiency P of Genotypes >79.64% was IR-75885-25-1-3-B-5-1-2-B-B (82.68%), UNRAM 1E (84.92%), UNRAM 9E (88.26%), Unsoed G12 (87.26%), IR 80340-23-B-B-1-B-B (88.45%), UNRAM 4E (88.69%), Unsoed G13 (89.99%), Unsoed G39 (91.09%), Unsoed G10 (92.08%), dan Unsoed G9 (94.31%).

Tabel 4. Dry weight of shoot (g) of upland rice genotypes at 30 days harvested and calculating of efficiency P under application of different P doses

Genotype	Dry weight of shoot (g)		P Eficiency (%) (P20/P80)
	P20	P80	
Situ Patenggang	1.8071	1.8200	99.29
UNRAM 4E	1.5292	1.7242	88.69
Unsoed G19	0.7608	1.5224	49.97
B-126-44F-MR-2	1.6963	2.2438	75.60
Unsoed G136	1.1408	1.4625	78.00
UNRAM 17E	1.4955	2.5931	57.67
B-124-98C-MR-1	1.8720	2.3584	79.38
UNRAM 1E	1.9640	2.3127	84.92
IR 80340-23-B-B-1-B-B	1.8103	2.0468	88.45
IR 77379-33-3-7-19-1-B	1.7999	2.7824	64.69
IR 75885-25-1-3-B-5-1-2-B-B	2.0711	2.5051	82.68
IR 75885-26-2-3-B-18-B-2-1-B	1.2859	1.8282	70.34
Unsoed G12	2.2595	2.5894	87.26
Unsoed G13	2.5447	2.8278	89.99
Unsoed G9	2.0398	2.1629	94.31
Unsoed G34	1.8146	2.5761	70.44
Unsoed G35	1.7267	2.1759	79.36
UNRAM 9E	2.3205	2.6293	88.26
Unsoed G10	1.7889	1.9427	92.08
Unsoed G39	1.6842	1.8492	91.08
Average			79.64

Remarks: P20 = 20 ppm P (deficient); P80 = 80 ppm P (sufficient).

Based on shoot P content, P efficiency ranges from 49.23% (Unsoed G19) to 67.11% (Unsoed G39) (Table 5). Situ patenggang had the low values on P efficiency of <62%. Genotypes obtained P efficiency >61.29% i.e. B-124-98C-MR-1 (62.00%), B-126-44F-MR-2 (62.31%), UNRAM 17E (62.44%),

UNRAM 9E (62.49%), G34 (62.96%), G10 (63.12%), Unsoed G9 (64.55%), Unsoed G136 (64.72%), Unsoed G35 (65.28%) and IR 77379-33-3-7-19-1-B (65.46%).

Tabel 5. Content of P of upland rice genotypes at 30 days harvested and calculating of efficiency P under application of different P doses

Genotype	P content (%)		P Eficiency (%)
	P20	P80	(P20/P80)
Situ Patenggang	0.1602	0.2807	57.07
UNRAM 4E	0.4531	0.7773	58.29
Unsoed G19	0.4119	0.8366	49.23
B-126-44F-MR-2	0.4611	0.7400	62.31
Unsoed G136	0.4873	0.7529	64.72
UNRAM 17E	0.4968	0.7956	62.44
B-124-98C-MR-1	0.4840	0.7806	62.00
UNRAM 1E	0.4403	0.7306	60.27
IR 80340-23-B-B-1-B-B	0.4986	0.8144	61.22
IR 77379-33-3-7-19-1-B	0.4843	0.7398	65.46
IR 75885-25-1-3-B-5-1-2-B-B	0.5190	0.8606	60.31
IR 75885-26-2-3-B-18-B-2-1-B	0.4516	0.7976	56.62
Unsoed G12	0.4162	0.7471	55.71
Unsoed G13	0.4837	0.8012	60.37
Unsoed G9	0.5341	0.8274	64.55
Unsoed G34	0.5057	0.8032	62.96
Unsoed G35	0.5446	0.8343	65.28
UNRAM 9E	0.5292	0.8468	62.49
Unsoed G10	0.4860	0.7700	63.12
Unsoed G39	0.5413	0.8066	67.11
Average			61.29

Remarks: P20 = 20 ppm P (deficient); P80 = 80 ppm P (sufficient).

There was a different result between shoot dry weight and shoot P content as P efficient genotypes. Variation values on both analyses must be separated to select genotypes with the character of P efficient. Therefore, consistency values of genotypes were taken as selected genotype of P efficient (Table 6). Some genotypes showed the consistency i.e. Unsoed G9, UNRAM 9E, Unsoed G10 dan Unsoed G39.

Selection of P efficiency genotypes refers to Fageria and Baligar (1997) by which mentioned that biomass weight and P 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.

Tabel 6. Comparison of P efficiency (PE) on upland rice genotypes based on shoots dry weight and P content

Genotype	P Eficiency (%)	
	PE-1	PE-2
Situ Patenggang	99.29	57.07
UNRAM 4E	88.69	58.29
Unsoed G19	49.97	49.23
B-126-44F-MR-2	75.60	62.31
Unsoed G136	78.00	64.72
UNRAM 17E	57.67	62.44
B-124-98C-MR-1	79.38	62.00
UNRAM 1E	84.92	60.27
IR 80340-23-B-B-1-B-B	88.45	61.22
IR 77379-33-3-7-19-1-B	64.69	65.46
IR 75885-25-1-3-B-5-1-2-B-B	82.68	60.31
IR 75885-26-2-3-B-18-B-2-1-B	70.34	56.62
Unsoed G12	87.26	55.71
Unsoed G13	89.99	60.37
Unsoed G9	94.31	64.55
Unsoed G34	70.44	62.96
Unsoed G35	79.36	65.28
UNRAM 9E	88.26	62.49
Unsoed G10	92.08	63.12
Unsoed G39	91.08	67.11

Remarks: PE-1= P efficiency based on shoot dry weight (Tabel 4); PE-2= P efficiency based on shoot P content (Table 5).

Drought tolerance and P efficient Genotypes

The results of selection on drought tolerance and P efficiency showed a variation in different methods by which were applied. Situ Patenggang variety as a control had a high value index on drought tolerance but low in P efficiency and also the same result showed in other genotypes for drought tolerance (Tabel 3) and P efficiency (Table 6). In general, genotypes with the character of tolerance to drought tend low in P efficiency and vise versa. However, Unsoed G39 showed the superior in drought tolerance and P efficiency.

The selection for drought tolerance was done as a modification by compile two different methods. Selection for genotypes with the character of drought tolerance by using both methods was still limited apply. Hoping by using different method in selection would be resulted the selected genotypes accurately.

Due to these methods were done at laboratory and screen house level under limited and control condition, further evaluation is still need under field condition to select the proper genotype ones. Even though, those genotypes had potency as drought tolerant and P efficient, the further evaluation must be done under field condition with the characters of low P and low rainfall intensity.

Conclusion

Even though the inconsistency of results were obtained but some genotypes showed the fit results on both methods i.e. Unsoed G-19, B-126-44F-MR-2, IR-75885-25-1-3-B-5-1-2-B-B and Unsoed G-39 as drought tolerant genotypes and Unsoed G9, UNRAM 9E, Unsoed G10 and Unsoed G39 as P efficient genotypes. Generally, genotypes with the character of drought tolerant tend low P efficiency and vise versa, except Unsoed G39.

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References

Akinride, E.A. and T. Gaizer. (2006). Differences in performance and phosphorus-use efficiency of some tropical rice (*Oryza sativa* L.) varieties. Pakistan J. of Nutrition 5(3):208-211.

Amberger, A. (2000). Soil Fertilizer and Plant Nutrition in the Tropics and Sub Tropics. International Potash Institue Switzerland.

Barton, C.J. (1948). Photometric analysis on phosphate rock. Ind.Anal.Eng.Chem. 20:1068-1073.

Bouman, B.A.M., S. Peng, A.R. Castaòeda and R.M. Visperas (2005). Yield and water use of irrigated tropical aerobic rice systems. Agric.Water Manag. 74(2): 87-105.

Center of Research and Development. (2008). Opportunity to gain sustainable rice production. National Department of Agriculture. Bogor.

Dobermann, A., K.G. Cassman, C.P. Mamaril and J.E. Sheehy (1998). Management of phosphorus, potassium, and sulfur in intensive, irrigated lowland rice. Field Crop Res. 56:113-138.

Fageria, N.K., R.J. Wright and V.C. Baligar (1988). Rice cultivar evaluation for phosphorus use efficiency. Plant and Soil 111:105-109.

Fageria, N.K. and V.C. Baligar (1997). Upland rice genotypes evaluation for phosphorus use efficiency. J. Plant Nutrition, 20 (4): 499 – 509.

Forbes, J.C. and R.D. Watson (1994). Plants in Agriculture. Cambridge, Britain. pp. 72-78.

Gunes, A., A. Inal, M. Alpaslan and I. Cakmak (2006). Genotypic variation in phosphorus efficiency between wheat cultivars grown under greenhouse and field conditions. Soil Sci. Plant Nutr., 52(4):470 – 478.

Hirayama, M., Y. Wada and H. Nemoto (2006). Estimation of drought tolerance on leaf temperature in upland rice breeding. Breeding Sci. 56:47-54.

IRRI, (2002). Reference Guide - Standard Evaluation System for Rice IRRI Los banos. Philipines.

Kato, Y., H. Satoshi, K. Akiniko, J. Abe, K. Urasaki and J. Yamagishi (2004). Enhancing grain yield of rice (*Oryza sativa* L.) under upland conditions in Japan. 4th International Crop Science Congress, Brisbane, Australia.

Kirk, G.J.D., T. George, B. Courtois and D. Senadhira (1998). Opportunities to improve phosphorus efficiency and soil fertility in rainfed lowland and upland rice ecosystems. Field Crop Res. 56:73-92.

Lasalita-Zapico, F., Janmichaeben G. Miranda and Michelle F. Pare (2008). Physiological characterization for drought tolerance of selected rice varieties in Lake Sebu, Philippines. USM R & D.J., 16(1):13 – 16.

Li, Y., A. Lou, X. Wei and A.K. Chaudry (2009). Relationship between leaf acid phospatase activity and either P nutritional status or P efficiency in rice. Pakistan J.Botany 41(1):109-119.

Liu, G., H. Mei., X. Yu., G. Zou., H. Liu., M. L.i, L.Chen., J. Wu and L. Luo (2007). Panicle Water Potential, a Physiological Trait to Identify Drought Tolerance in Rice. J. Integr. Plant Biol. 49 (10): 1464–1469.

Ozturk, L., S. Eker., B. Torun, and I. Cakmak (2005). Variation in phosphorus among 73 bread and durum wheat genotypes grown in phosphorus-deficient calcareous soil. Plant and Soil, 269: 69–80.

Venuprasad, V., H.R. Lafitte and G.N. Atlin (2007). Response to direct selection for grain yield under drought stress in rice. Crop Sci. 47:285-293.

Wissuwa, M. (2003). How Do Plants Achieve Tolerance to Phosphorus Deficiency? Small Causes with Big Effects1. Plant Physiol. 133:1947–1958.

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