Estimation for Stress Tolerance Indices of Rice Genotypes in Low Nitrogen Condition

A.P. Lestari[1], Suwarno[1], Trikoesoemaningtyas[2], D. Sopandie[2] and H. Aswidinnoor[2,*]

[1] Indonesian Center for Rice Research, Indonesia

[2] Department of Agronomy and Horticulture, Institut Pertanian Bogor, Indonesia

* Corresponding author: hajrial@ipb.ac.id

Submission: 26 March 2018 Revised: 1 October 2019 Accepted: 26 November 2019

ABSTRACT

To overcome the highly use of nitrogen (N) fertilizer, it should be obtained the low N tolerant rice lines. Therefore, the selections under the condition of low N have to be carried out. The objective of this on-station experiment was to identify desirable rice genotypes suited to limited nitrogen availability based on stress selection indices. Twenty-six rice genotypes were evaluated under low N and optimum N environments. The experiment was conducted at Muara Experimental Farm Bogor in wet season 2014 and used augmented design with three replications for check varieties under low N and optimum N conditions. Seven stress tolerance indices including mean productivity (MP), geometric mean productivity (GMP) tolerance (TOL), yield stability index (YSI), stress tolerance index (STI), and stress susceptible index (SSI) were computed and analyzed based on grain yield under low N and optimum N conditions. Analysis of variance showed significant variations due to genotypes for grain yield under two N conditions. Principal Component Analysis (PCA) showed that the first PCA explained 69.5.0% of MP, GMP, STI and TOL. PCA indicated that the first two components accounted for more than 98% of the total variations for low N tolerant indices. Positive and significant correlation of Ys and Yp with MP, GMP, and STI concluded that these indices were the best predictors of yield under low N and optimum N environments. According to MP, GMP, and STI genotypes code 1, 4, 5, 7, 8, 9 and 12 were the most tolerant genotypes under low N conditions. Genotypes no 1, 4, 5, 7, 8, 9, 14 and 26 were superior genotypes for both N conditions.

Keywords: Rice, grain yield, low N, stress indices

Thai J. Agric. Sci. (2019) Vol. 52(4): 180−190

INTRODUCTION

As the most important nutrient for plant growth, nitrogen (N) application is needed for obtaining high yield. N deficiency causes impaired development of the plants such as chlorosis, reduced the number of tillers, grain weight and yield. However, N is the most limiting nutrient in the soil due to plant transporting at harvest time activity (Mei-Hua *et al*., 2012) and also because of its characters, such as easy to leach and to volatilize (Zhong-cheng *et al*., 2012), and denitrificate (Choudhury and Kenedy, 2005). Tolerant rice variety is capable to translocate N into grain during the formation and development of the generative organs (Anwar and Darjanto, 2009).

To obtain low N tolerant rice lines, the selections under the condition of low N have been carried out (Gallais and Coque, 2005). Some researchers said that to get the tolerant lines selection activity should be performed at the optimum N selection condition (Le Gouis *et al*., 2000; Reynolds and Borlaug, 2006; Ortiz *et al*., 2008, Moosavi *et al*., 2008). Several selection parameters have been used by researchers based on stress selection indices under optimum and stress conditions to identify the tolerant rice genotypes for drought (Kondhia *et al*., 2015), wheat (Khan and Mohammad, 2016) and maize (Presterl *et al*., 2003) under nitrogen stress, wheat under heat stress (Shefazadeh *et al*., 2012), barley under water stressed condition (Khokhar *et al*., 2012), Tef (Shiferaw *et al*., 2012), and rapeseed (Aliakbari *et al*., 2014).

A number of research outputs showed that nitrogen fertilizers increased the rice yield (Ye *et al*., 2007). Nitrogen fertilizer requirements differ significantly according to soil type, climate, management practice, timing of nitrogen application and cultivars used. There were several yield-based stress indices have been developed those may be more applicable for nitrogen deficiency stress environment (Rameeh, 2015).

Several selection parameters have been proposed to choose genotype based on the grain yield under stress and optimal conditions. Many studies have used tolerance indices to select stable genotypes according to their performance under favorable and stress conditions. There are some selection criteria including stress susceptibility index (SSI), mean productivity (MP), tolerance index (TOL), geometric productivity (GMP), stress tolerance index (STI), and yield stability index (YSI) (Mohammadi *et al*., 2010). The higher value of MP, GMP and STI for a genotype indicates its stress tolerance level and yield potential (Mollasadeghi *et al*., 2013). MP is the average productivity of the genotypes in stress and optimum conditions. GMP is a relative value because stress can vary each time and STI can be used to identify high yield-genotypes under both stress and optimum conditions (Syafi'i *et al*., 2016).

A larger value of TOL represents relatively more sensitivity to stress, thus a smaller value of TOL is favored. The stress susceptibility index (SSI) is a ratio of genotypic performance under stress and non-stress conditions, adjusted for the intensity of each trial (Kumar *et al*., 2014). The objectives of this study were (1) to compare and evaluate different yield-based N tolerance selection indices and (2) to identify the most stable high-yielding lines under both N conditions environments.

MATERIALS AND METHODS

A field experiment was carried out at Muara Experimental Farm, Bogor, Indonesia with altitude of about 200 m above sea level. The soil of the field is oxisols (latosol). The soil analysis was shown in Table 1. There were twenty-six rice lines, from crossing between new varieties and local varieties, and six check varieties were used. The experiment was designed as augmented with three replications of the checks under low N (34.5 kg N/ha N) and optimum N (138 kg N/ha). Grain yields were recorded from 5 m2 plots, for each rice genotypes and converted to t/ha. The data were analyzed using Microsoft Excel and Minitab software. Tolerance indices were calculated as follows (Meena *et al*., 2015; Khan and Mohammad, 2016):

Tolerance (TOL) $= Yp - Ys$

Stress index (SI) $= 1 - \frac{\overline{Ys}}{\overline{Yp}}$

Stress susceptible index (SSI) $= \frac{(1 - \frac{Ys}{Yp})}{SI}$;

Mean productivity (MP) $= \frac{Yp + Ys}{2}$

Geometric mean productivity (GMP) $= \sqrt{Yp \times Ys}$

Stress tolerance index (STI) $= \frac{Yp \times Ys}{\overline{Yp}^2}$

Yield stability index (YSI) $= \frac{Ys}{Yp}$

where Ys is grain yield of each genotype under low N condition, Yp is grain yield of each genotype under optimum N condition, and are the mean yields of all genotypes under low N and optimum N, respectively. Correlation analyses were conducted using yield and yield components data and calculated quantitative indices of stress tolerance. Estimated grain yield of a specific genotype i, Y_i, was derived from a multiple regression analysis (Akbarabadi *et al*., 2015) as follow:

$$Y_i = a + bY_{pi} + cFL_i$$

where Y_{pi} is the potential grain yield of genotype i, as measured under the normal treatment, FL_i is the character of genotype i under the normal treatment, and a, b, c are regression parameters.

Table 1 Soil analysis of field experiment

No	Character	Value	Criteria*
1	C-org (%)	1.80	Low
2	N-total (%)	0.19	Low
3	C/N	9.00	Low
4	P_2O_5 HCl 25% (ppm)	144.00	High
5	P_2O_5 Bray 1 (ppm)	7.10	Low
6	K (me/100g)	0.47	Medium
7	Mg (me/100g)	1.76	Medium
8	Ca (me/100g)	7.88	Medium
9	KTK (me/100g)	15.02	Low
10	pH	5.30	Acid

Note: *Hardjowigeno (2003)

Principal component analy sis (PCA) was partitioned by the AMMI model and conducted using data recorded on yield and quantitative indices of stress tolerance. It was performed by Minitab ver.16. The model was performed by Zeleke and Berhanu (2016) as below:

$$Y_{ij} = \mu + G_i + E_j + (\textstyle\sum_1^n K_n U_{ni} S_{ni}) + Q_{ij} + \bar{\varepsilon}_{ij}$$

where, Y_{ij} is the mean yield across replicates of the genotype i in the j environment, μ is the grand mean, G_i is the additive effect of genotype i, E_j is the additive effect of environment j, K_n is the singular value of the IPCA axis n, U_{ni} and S_{jn} are values of genotype i and environment j for the IPC axis, respectively, Q_{ij} is residual for the first multiplicative components and $\bar{\varepsilon}_{ij}$ is the residual error.

RESULTS AND DISCUSSION

Analysis of Variance and Genotypes Performace

The results of analysis of variance for grain yield under suboptimum and optimum N environments are presented in Table 2. Mean squares in each condition indicated significant differences among all genotypes for yield, due to genotypes responding to the suboptimum N environments. Different responding genotypes facilitated for selecting a tolerant genotype to low N environment.

Table 2 Analysis of variance for yield of rice lines under N suboptimum (N-) and N optimum (N+) environments

Source of variation	df	Mean square	
		N-	N+
Block	2	0.31	0.04
Genotype	31	1.45*	2.51
Check	5	1.39	1.95
Error	10	0.55	1.07
Total	43		
CV(%)		17.50	21.90

Note: * = significant at α 0.05

Tolerance indices were calculate on the basis of the genotypes and outputs are presented in Table 3. Genotypes showed wide range variations for the estimated indices. The mean yield of genotypes under low N environment varied from 1.63 to 6.13 t/ha, while mean of yield genotype under optimum N environment varied from 3.13 to 8.43 t/ha. Several genotypes showed higher yield than best check variety Inpari 23 under low N condition and this result suggested that those genotypes were potentially to be a tolerant genotype. The genotypes 1, 4, 7, 8, 12 and 13 had the best performace of grain yield in low N condition, while genotypes with the best performance under optimum N than check verieties were 1, 2 , 3, 4, 5, 6, 7, 8, 9, 12, 14, 20, 21, 24, 25 and 26. Genotypes 1, 4, 7, 8 and 12 were least tolerant because it showed very lower yield under low N while high yield under optimum N.

Based on the tolerant indices, the identification of tolerant genotypes based on a single criterion was contradictory. According to STI, MP, and GMP genotypes 1, 4, 5, 7, 8, 9 and 12 were the most tolerant genotypes. For SSI and YSI the desirable low N tolerant genotypes were 2, 3, 9, 10, 11, 12, 14, 15 and 1, 4, 5, 6, 7, 8, 13, respectively. TOL had defined that 2, 3, 9, 10, 12, 14, 16, 17 and 18 were the tolerant genotypes. STI, MP and GMP had different result from SSI and YSI. However, TOL had similar result with STI, MP and GMP only for genotype no 9 and 12. TOL also had similar result with SSI for genotypes no 2, 3, 9, 10 and 12.

Correlation between Grain Yield and Tolerance Indices

To determine the most desirable tolerance criteria, the correlation coefficient between quantitative low N tolerance indices to Ys and Yp were presented in Table 4. Ys showed positive correlation with Yp, MP, GMP, STI and YSI while had negative correlation with SSI and TOL. The positive correlation between Yp and Ys indicates that selection under non-stress environment may give high yielding genotypes under stress environment (Shiferaw *et al.*, 2012). Yp showed positive correlation with MP, TOL, GMP and STI. Highly significant and positive correlation were observed among each pair of MP, GMP and STI. This suggested that selection based on those indices values will increase grain yield under optimum N environment and it was showed in Table 2, as describe before, that line no 1, 4, 5, 7, 8, 9 and 12 was the most tolerant genotype of other lines based on MP, GMP and STI. This result was similar with other reports (Sio-Se Mardeh *et al.,* 2006; Talebi *et al*., 2009).

Table 3 Mean value of low N tolerance indices for 40 rice genotypes at N suboptimum and N optimum environments

No	Genotype	Ys	Yp	SSI	MP	TOL	GMP	STI	YSI
1	BBS14250F-15-4	5.85	6.25	0.36	6.0	0.4	6.0	6.04	0.94
2	BBS14250F-6-2	4.53	6.29	1.55	5.4	1.8	5.3	5.34	0.72
3	BBS14250F-14-1	3.38	5.98	2.42	4.7	2.6	4.5	4.50	0.57
4	BBS14250F-2-10	6.13	6.05	-0.07	6.1	-0.1	6.1	6.09	1.01
5	BBS14250F-6-6	5.53	5.62	0.09	5.6	0.1	5.6	5.58	0.98
6	BBS14250F-3-1	4.87	5.14	0.29	5.0	0.3	5.0	5.00	0.95
7	BBS14250F-14-10	5.98	6.10	0.10	6.0	0.1	6.0	6.04	0.98
8	BBS14250F-5-3	5.73	6.15	0.37	5.9	0.4	5.9	5.94	0.93
9	BBS14250F-12-7	5.16	6.08	0.84	5.6	0.9	5.6	5.60	0.85
10	BBS14250F-6-1	3.94	5.02	1.20	4.5	1.1	4.4	4.45	0.78
11	BBS14250F-7-9	3.26	3.86	0.87	3.6	0.6	3.5	3.55	0.84
12	BBO14250F-9-9	5.80	8.43	1.74	7.1	2.6	7.0	7.00	0.69
13	BBO14250F-8-3	5.73	5.20	-0.57	5.5	-0.5	5.5	5.46	1.10
14	BBO14250F-12-7	4.39	5.71	1.29	5.0	1.3	5.0	5.00	0.77
15	BBO14250F-12-4	3.93	4.54	0.75	4.2	0.6	4.2	4.22	0.87
16	BBO14250F-16-2	1.71	3.28	2.67	2.5	1.6	2.4	2.37	0.52
17	BBO14250F-6-2	1.63	3.82	3.19	2.7	2.2	2.5	2.50	0.43
18	BBO14250F-6-7	2.07	4.58	3.05	3.3	2.5	3.1	3.08	0.45
19	BBO14250F-9-7	2.83	5.29	2.59	4.1	2.5	3.9	3.87	0.53
20	BBO14250F-5-3	1.85	8.30	4.33	5.1	6.5	3.9	3.92	0.22
21	BBO14250F-3-7	4.08	6.29	1.96	5.2	2.2	5.1	5.06	0.65
22	BBO14250F-3-2	2.74	4.85	2.42	3.8	2.1	3.6	3.65	0.56
23	BBO14250F-8-2	2.01	3.13	1.99	2.6	1.1	2.5	2.51	0.64
24	BBO14250F-13-4	2.07	5.73	3.56	3.9	3.7	3.4	3.44	0.36
25	BBO14250F-4-7	2.74	5.94	3.00	4.3	3.2	4.0	4.03	0.46
26	BBO14250F-5-2	4.95	6.02	1.89	5.5	1.1	5.5	1.26	0.82
Check1	IR77674	4.60	5.17	1.18	4.9	0.6	4.9	1.01	0.89
Check2	Asahan	4.32	4.54	0.52	4.4	0.2	4.4	0.83	0.95
Check3	Ciherang	3.92	4.29	0.91	4.1	0.4	4.1	0.71	0.91
Check4	Inpari 6	4.85	5.26	0.82	5.1	0.4	5.1	1.08	0.92
Check5	Inpari 23	5.56	5.37	-0.39	5.5	-0.2	5.5	1.27	1.04
Check6	Inpari 33	3.66	3.97	0.83	3.8	0.3	3.8	0.62	0.92

Note: Ys = grain yield under low N condition, Yp = grain yield optimum N condition, SSI = Stress susceptible index, MP = Mean productivity, TOL = Tolerance, GMP = Geometric mean productivity, STI = Stress tolerance index, YSI = Yield stability index

The most closely correlated to Ys and Yp were MP, GMP and STI. Therefore, through these indices it is possible to distinguish high yielding genotypes in low N as well as optimum N condition. Aliakbari *et al*. (2014) suggested that if no significant correlation between yield under non-stress with tolerant indices indicating that those indices were not good indicators to identify the genotype with high yield potential. Khan and Mohammad (2016) also reported that the stress indices including GMP, MP and STI were highly correlated with each other as well as with Ys and Yp.

Table 4 The correlation coefficient between Ys and Yp with various tolerance indices

	Ys	Yp	SSI	MP	TOL	GMP	STI
Yp	0.415*						
SSI	-0.842*	0.103					
MP	0.871*	0.808*	-0.490*				
TOL	-0.654*	0.417*	0.927*	-0.199			
GMP	0.940*	0.693*	-0.616*	0.982*	-0.363*		
STI	0.940*	0.693*	-0.616*	0.982*	-0.363*	1.000	
YSI	0.842*	-0.103	-1.000	0.490*	-0.927*	0.616*	0.616*

Note: * = significant at α 0.05
Ys = grain yield under low N condition, Yp = grain yield optimum N condition, SSI= stress susceptible index, MP = mean productivity, TOL = tolerance, GMP = geometric mean productivity, STI = stress tolerance index, YSI = yield stability index

Relationship Between Grain Yield and Tolerance Indices

The linear regression revealed that coefficients of determination between Ys and the tolerance indices were $R^2_{GMP/Ys}$ = 0.8831, $R^2_{MP/Ys}$ = 0.7593, $R^2_{STI/Ys}$ = 0.8574, $R^2_{YSI/Ys}$ = 0.7092 (Figure 1). These results revealed that GMP, MP, and STI indices may be considered to be the best predicate to explain grain yield variations under low N condition. However, relationship between Ys with TOL and SSI were negatively significant with coefficient determination were $R^2_{TOL/Ys}$ = 0.4277 and $R^2_{SSI/Ys}$ = 0.7092. It showed that TOL and SSI cannot use as grain yield variation under low N condition. In general, our results revealed that according to correlation analysis other indices such as STI, MP, and GMP can be used as the most suitable indicators for screening tolerant cultivars.

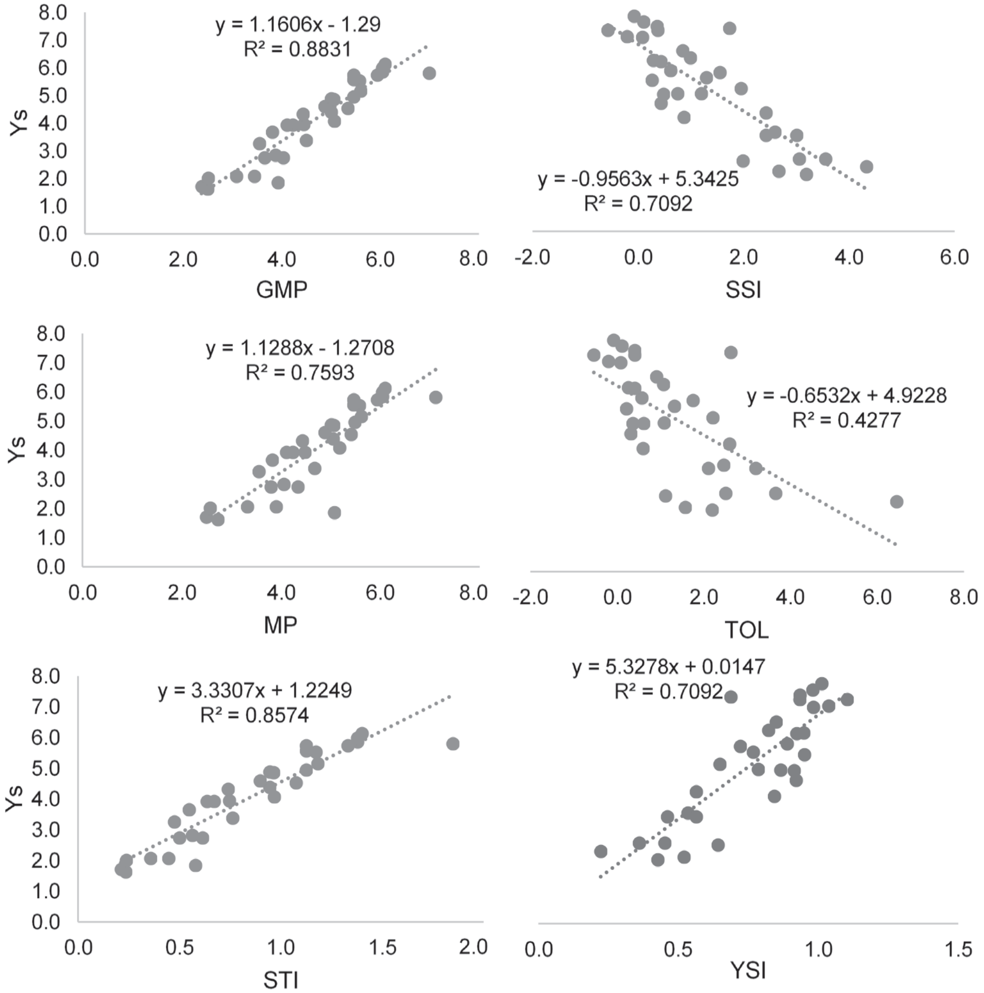

Figure 1 Relationship between grain yield in low N condition (Ys) and (a) stress tolerance index (STI), (b) geometric mean productivity (GMP), (c) yield stability index, and (d) stress tolerance (TOL), (e) mean productivity (MP) and (f) stress susceptability index (SSI)

Principal Component Analysis

Principal Component Analysis (PCA) is a way to compress data sets of high dimensional into lower dimensional ones (Abdi *et al.,* 2013). The biplot presentation showed high genotype variability among studied rice lines (Figure 2). There were positive and high significant correlations among yield in low N conditions (Ys) with some tolerance indices such as YSI and SSI, but those YSI and SSI components had negative correlation with TOL. A high and significant positive correlation was observed between MP, GMP and STI. PCA is used in order to asses the relationship between all tolerance indices to identify superior genotypes at once (Table 5). The first (PC1) and second (PC2) components justified 69.5% and 29.8%, respectively and accounted for 99.3% of total variation. PC1 had positive correlation with Ys, Yp, MP, GMP, STI and YSI. The PC2 correlated positively with SSI and TOL.Genotypes that have high PC1 and low PC2 are suitable for both low and optimum N conditions. Genotypes with code number 1, 4 , 5, 7, 8, 9, 14 and 26 also check varieties Inpari 6 and Inpari 23 were superior genotypes for both conditions (codes see Table 3).

Table 5 Principal component analysis Ys, Yp and low N tolerance indices of rice lines

Variable	PC1	PC2
Ys	0.423	-0.015
Yp	0.186	0.580
SSI	-0.355	0.347
MP	0.375	0.303
TOL	-0.268	0.497
GMP	0.401	0.205
STI	0.401	0.205
YSI	0.355	-0.347
Eigen value	5.560	2.382
Proportion (%)	0.695	0.298
Cumulative (%)	0.695	0.993

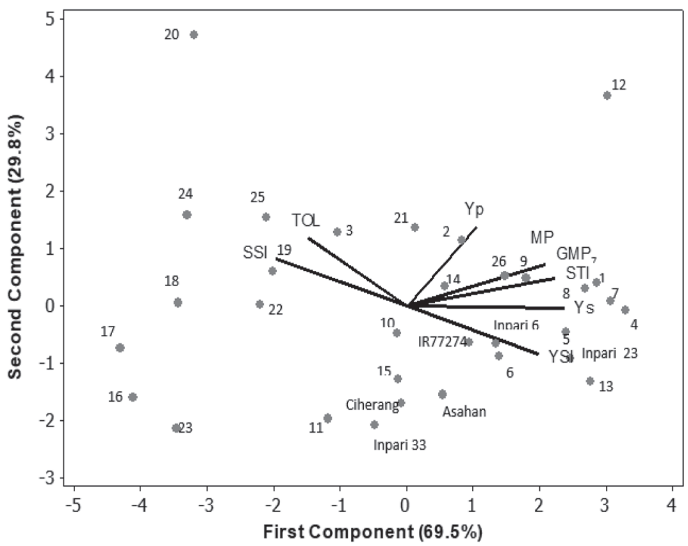

Figure 2 Principal component analysis of genotypes distribution base on stress tolerance indices

In order to identify the tolerant cultivars, three dimensional plots were presented in Figure 3 that used MP, GMP and STI indices according to analysis before that those three indices were the best for indicating tolerant genotypes. Three dimensional plots are presented to separate the cultivars of group A from the other groups i.e. B, C and D (Tarabideh *et al*., 2014). No. 20 were in A group that represented to high yielding cultivars in both low and optimum N conditions. The no. 16, 17 and 23 were in D group that performed poorly in both conditions.

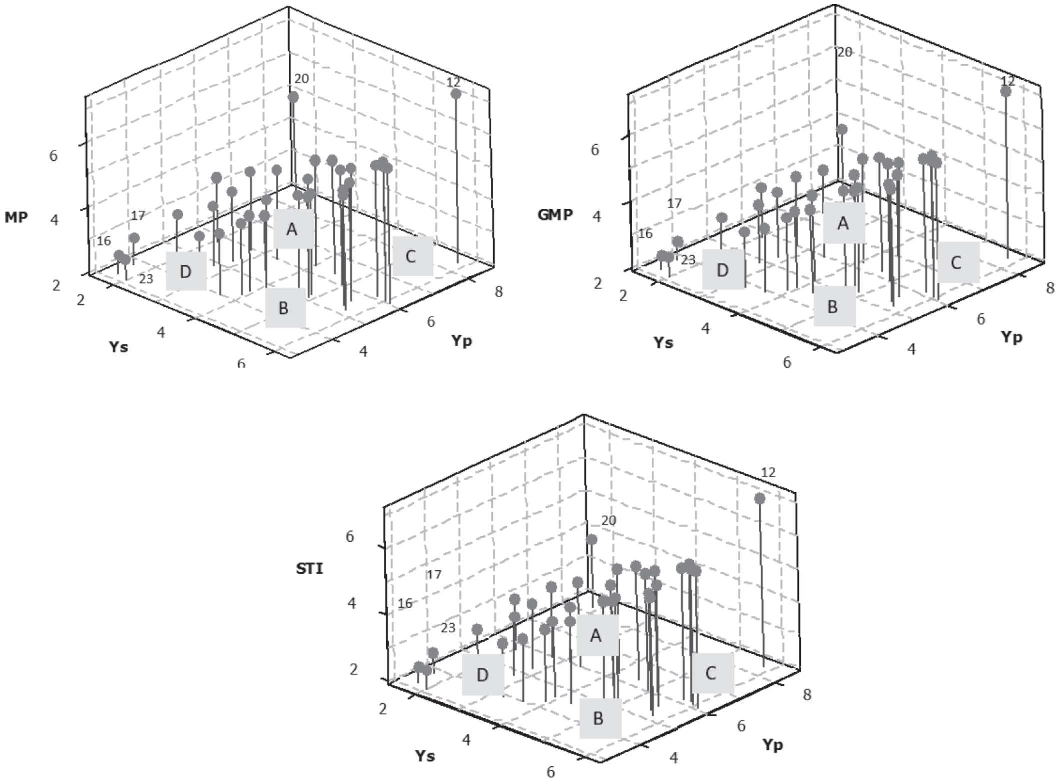

Figure 3 Three dimensional bi-plot showing interrelationship of Yp, Ys and MP (top), GMP (middle), and STI (bottom)

CONCLUSION

There were significant variations due to genotypes for grain yield in low N conditions. Selection using these indices was useful for identifying a genotype with desirable yield under both N conditions. Correlation between indices of N tolerance and yield in both conditions identified that STI, MP, and GMP were the most suitable indicators for screening low N tolerant genotypes. Line no. 1, 4, 5, 7, 8, 9 and 12 were the most tolerant genotypes of than the other lines based on MP, GMP and STI. Based on yield under low N condition, the genotypes 1, 4, 7, 8, 12 and 13 were the best performing genotypes. Genotypes no 1, 4 , 5, 7, 8, 9, 14 and 26 were superior genotypes on low and optimum N conditions. These conclude that lines no 1, 4, 7 and 8 were stable under both N conditions.

ACKNOWLEDGMENTS

The authors would like to appreciate to Indonesian Agency for Agricultural Research and Development (IAARD), Ministry of Agriculture of Indonesia for financial support and Mr. Supartopo, Mr. Sukirman, Mr. Oma, Mr. Djadjuli, Mr. Tomi for data collecting during the experiment.

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