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ADDITIVE MAIN EFFECT AND MULTIPLICATIVE INTERACTION ON FIXED MODEL OF TWO FACTORS DESIGN

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Abstract

Multilocation trials is usually conducted to study the factors effect of genotype and environment including their interaction in order to increase the yield of crops. The environment can be considered as giving different doses of fertilizers to each genotype. The present study was aimed to investigate both additive main and interaction effects on fixed model of two factors design. As the application, the study used a dataset of the yield of paddy in four varieties (IR8, IR5, C4-63, and PETA) given nitrogen fertilizer with six different doses ($N_{0,}$ N_1, N_2, N_3, N_4, and N_5). The first step of analysis was estimating variance component using fixed model ANOVA (*Analysis of Variance*). Then, AMMI (*Additive Main Effects and Multiplicative Interaction*) model was applied which is the combination of additive main effect and the principal component analysis (PCA) of interaction effect. The result of study shows that the variance component has positive value for all factors of treatment. AMMI analysis produces AMMI-2 as the best model at the significant level of $\alpha = 0.05$. The biplot of AMMI-2 obtained that IR5 can adapt to nitrogen fertilizer in any level. Spesific interaction occurs in variety C4-63 in nitrogen N_4 level, variety IR8 in nitrogen N_5 level, and variety PETA in nitrogen N_0 level. Based on the result of study, it can be concluded that the use of AMMI fixed model in two factors design can effectively explain the effect and the pattern of interaction structure among treatment factor levels.

Keywords: AMMI, ANOVA, Genotype, Multilocation, PCA

Introduction

Factorial experimental design such as multi-location trials is often used in plant breeding research to examine the interaction of treatment factors. The factors are involved in multi-location trials, namely genotype and location. Location here can be interpreted as different doses fertilizers in a particular environment. Therefore, with this multi-location trials, stability of genotypes in a variety of different environments or adaptation of genotypes to specific environmental can be known.

In agriculture, grain yield which is not consistent with the environment changes is an indication of the interaction of genotype and environment. Carelessness in analysis of the genotype and environment interaction may lead to the removal of high yielding varieties in the selection process. Various methods have been used for the analysis and to assess the stability of a genotype result in a wide range of environments. The reliability of the analysis will be able to provide accurate conclusions in selecting high yielding genotypes and able to adapt to environmental conditions. The common statistical analysis applied to the multi-location trials is Additive Main Effects and Multiplicative Interaction (AMMI). AMMI method is a combination of analysis of variance (ANOVA) for the main effect and principal component analysis (PCA) for interaction effects (Matjjik, 1996 and Widiastuti, 2010).

ANOVA in the AMMI method aims to determine whether there is any effect of varieties to different fertilizers doses. According to Steel & Torrie in Mattjik (1998), analysis of variance is an arithmetic process to decompose the total sum of squares into components associated with a known source of variation. Flexibility and the ability to decompose the diversity of interaction effects AMMI models using analysis based on principal component analysis which statistically has been able to sort out the effect of the interaction of the components that are orthogonal principal. In accordance with the definition of principal component analysis by Johnson and Wichern (1996) and Matjjik (2004), which attempts to reduce the *p* variable observation into *k* new variable which is orthogonal that each of the *k* new variables are linear combinations of the *p* old variables.

Furthermore, in presenting the pattern of genotyping scatter plots with the relative position to the various doses of fertilizer, the singular value decomposition were plotted between one genotypes component with fertilizer component simultaneously. A display in the form of plot is so-called biplots. AMMI analysis thus can improve the accuracy of the alleged response by genotype environment interaction and AMMI able to summarize the patterns and relationships between genotypes, environments, and the interaction both of genotype and environment.

Based on the problem described above, the objectives of this study were (1) to estimate the mean square of the expected value and variance components and (2) to apply AMMI models to the paddy crop yield.

Materials and Methods

As an illustration of the application, this study used the data in the form of paddy crop yield of 4 (four) varieties (IR8, IR5, C4-63, and PETA) were given nitrogen fertilizer with 6 (six) different doses (N_0, N_1, N_2, N_3, N_4, and N_5). This data was obtained from the book of Statistical Procedures for Agricultural Research, Second Edition by Kwanchai A. Gomez and Arturo A. Gomez, 1995.

In developing AMMI model, firstly, the mean square value estimation and variance components were made in the design of two-factor model of paddy crop yield. According to Suwardi *et al*., (2001), the method used to estimate the mean square of expected value and variance components in the design of the two-factor is the method of two-factor ANOVA with interaction. The design is as follows.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}, \ (i=1,2,\ldots g;\ j=1,2,\ldots l;\ k=1,2,\ldots r) \qquad (1)$$

where:

Y_{ijk}	:	an observed value for factor A i-th level, factor B j-th level, and in k-th level
μ	:	overall mean
α_i	:	effect of factor A in i-th level
β_j	:	effect of factor B in j-th level
$(\alpha\beta)_{ij}$	:	effect of interaction AB in i-th level and j-th level
ε_{ijk}	:	trial errors

Model assumptions, namely; error (ε_{ijk}) is a random effect that spreads normally, to the fixed model: $\sum_{i=1}^{g} \alpha_i = 0, \sum_{j=1}^{l} \beta_j = 0\, , dan\ \sum_{k=1}^{r} (\alpha\beta)_{ij} = 0,$ (Sumantri, 1997).

Furthermore, ANOVA was also used to determine the effect of the main and interaction effects. In this stage, the effect of the interaction is decomposed into several principal components which are significant at the level of α = 0.05, that resulting AMMI models.

Basically AMMI models incorporate additive analysis of variance for the main effect of treatment with multiple principal component analysis with bilinear modeling for the interaction effect (Zobel and Crossa in Sumertajaya, 2007) and (Matjjik, 2998). Therefore, the complete AMMI models can be written as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \sum_{n=1}^{m} \sqrt{\lambda_n}\varphi_{in}\rho_{jn} + \delta_{ij} \qquad (2)$$

where: $\sqrt{\lambda_n}$ is the singular value for the n-th bilinear component ($\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_n$, φ_{in} is a ripple effect of factor A i-th level through the bilinear component n-th, ρ_{jn} is a double impact factor B through bilinear component n, δ_{ij} is the deviation from bilinear modeling.

In AMMI modeling, the additive effect of factor A and factor B and the sum of the squares and the mean square is generally calculated as the analysis of variance, but based on the average by a factor A to factor B. The results of the calculation of the sum of squares, mean squares and principal component interactions can arranged in a structure AMMI ANOVA. To interpret the results of the AMMI analysis, biplot method will be used by overlapping vectors in two-dimensional space. AMMI biplot will explain stable adapted varieties to different environments or adapt to a specific environment.

Results and Discussion

Estimating the expected value and the mean square of the variance component with ANOVA fixed models method to the data on grain yield of four rice varieties by giving six different nitrogen doses resulted in a positive variance components (Table 1). These results indicate that the method can be used to estimate for the variance component data used.

Table 1. Estimation of Mean Square Expected Values and Variance Component

Source of Variance	Mean Squares Expected Value	Variance Component
α	$18{\sigma_\alpha}^2 + {\sigma_\varepsilon}^2$	1647132,51
β	$12{\sigma_\beta}^2 + {\sigma_\varepsilon}^2$	480960,40
$\alpha\beta$	$3{\sigma_{(\alpha\beta)}}^2 + {\sigma_\varepsilon}^2$	1436194,65
ε	${\sigma_\varepsilon}^2$	314315,18

Furthermore, to apply AMMI method, the analysis of variance is done to determine the main factor effect of paddy varieties and the main factor effect of nitrogen fertilizer. The results of the analysis of variance in Table 2 shows that the main effect (varieties and fertilizers) and the interaction effect significantly at the level of α = 0.05. These results indicate that the grain yield of paddy varieties influenced by the factors of nitrogen fertilizer. That is why AMMI analysis is needed to identify paddy varieties that interact positively with certain nitrogen doses.

Table 2. Two Factors ANOVA for both Varieties and Fertilizer

Source of Variance	Degree of Freedom	Sum of Square	Mean Square	*F*-value	*p*-value
Varieties (paddy)	3	89888101,15	29962700,38	95,32	0.0001

Fertilizer (nitrogen)	5	30429199,57	6085839,91	19,36	0.0001
Interaction	15	69343486,93	4622899,13	14,70	0.0001
Error	48	15087128,7	314315,18	-	-
Total	71	204747916,3	-	-	-

The process of singular value decomposition (SVD) of the interaction effect produced six singular values. The variance contributions of all principal components (PC) for the AMMI models are shown in Table 3.

Table 3. Contributions of Variance for the Principal Component of AMMI Model

PC	Singular Value	Eigen Value	Proportion	Cumulative
1	4647,92	21603189,14	0,94	0,94
2	1156,68	1337908,16	0,06	0,99
3	416,42	173401,24	0,01	1,00
4	1,247e-13	1,55e-26	0,00	1,00
5	0,00	0,00	0,00	1,00
6	0,00	0,00	0,00	1,00

The results of ANOVA for AMMI are obtained by the contribution of the diversity of the main components in Table 3 above can be presented in Table 4. Results of ANOVA are obtained two components with a *F*-value = 29.45 and *p*-value = 0.0001 at the significant level of α = 0.05 on the first principal component. Similarly, the second principal component of the interaction is significant level at α = 0.05 level with a *F*-value = 2.55 and *p*-value = 0.0001. These results show that the first two of PC are significant, so that the model AMMI-2 is applicable. This indicates that the data are four varieties of paddy grain yield of six nitrogen level can be explained by using a model AMMI-2 as the best model.

Table 4. ANOVA of AMMI-2 Modeling

Source of Variance	Degree of Freedom	Sum of Square	Mean Square	*F*-value	*p*-value
Varieties (paddy)	3	89888101,15	29962700,38	95,32	0.0001
Fertilizer (Nitrogen)	5	30429199,57	6085839,91	19,36	0.0001
Interaction	15	69343486,93	4622899,13	14,70	0.0001
PC-1	7	64809567,42	9258509,63	29,45	0.0001
PC-2	5	4013724,48	802744,90	2,55	0.0001
Deviation	3	520195,03	65024,38	-	-
Error	48	15087128,70	314315,18		
Total	71	204747916,30	-	-	-

Fig. 1 shows the biplot between PC-1 with PC-2. This biplot explained that the paddy varieties type C4-63, IR5, and IR8 have a major effect which is relatively the same because they are on the same vertical line. Furthermore, C4-63 and IR5 have the same relative effect of the interaction as it is located on a horizontal line. Similarly, IR8 and PETA also have a relatively similar interaction effect.

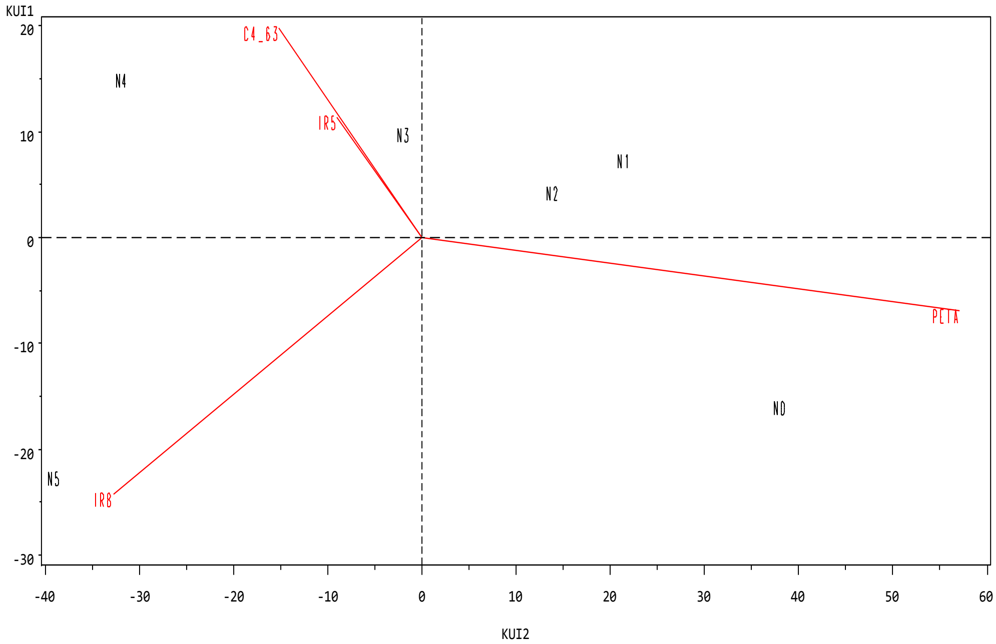

Figure 1. Biplot of AMMI-2 Model

Nitrogen doses $N_3, N_4,$ and N_5 have main effect which is relatively the same but have different interactions effect. In $N_0, N_1,$ and N_2 also have the same main effect, but N_0 has different effect interactions. PETA varieties are positively interact with $N_0, N_1,$ and N_2 because having the same direction. Similarly, varieties of C4-63, IR5 and IR8 are positively interact with $N_3, N_4,$ and N_5.

Biplot PC-1 with PC-2 also shows that IR5 is having a diversity at a relatively small so that all levels of nitrogen can be applied well on the rice varieties. In other words, IR5 was widely adaptable to all levels of nitrogen. While IR8 and PETA have specific adaptations to particular nitrogen level because it is at the furthest point of intersection of the zero point. Furthermore, C4-63 variety is specifically interacted at the level of nitrogen N_4, IR8 variety is specifically interacted at the level of nitrogen N_5, and the PETA variety is specifically interacted at the level of nitrogen N_0.

Conclusion

The results of the variance component estimators give a positive value on each factor effects of treatment. Therefore, ANOVA fixed models method can be used to assume variance components for data of grain yield of four paddy varieties to six nitrogen doses level. ANOVA resulted in a real effect on the significant level at α = 0.05 for the main effects of varieties of fertilizers and nitrogen doses as well as their effect of interactions.

Based on the ANOVA for the AMMI models, it produces two main components interaction significant at the level 0.05 significance level in order to obtain a model AMMI-2 which is the best model. AMMI-2 biplot interpretation is concluded that IR5 has the diversity of a relatively small so that it can adapt to all levels of nitrogen wide. The specific interaction occurs in C4-63 varieties at the level of nitrogen N_4, IR8 varieties at the level of nitrogen N_5, and PETA varieties at the level of nitrogen N_0.

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