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# Using Regression Indices and Multiple Criteria Analysis for Study of Some Rice Genotypes under Interaction of Variable Environmental Conditions

**Atif Elsadig Idris[1*], Khalid A. Mohamed[2] and Hassan Ibrahim Mohammed[3]**

*[1]Department of Agronomy, College of Agricultural Studies, Sudan University of Science and Technology, Shambat, P.O. Box 71, Khartoum North, Sudan.*
*[2]Faculty of Agriculture and Natural Resources, University of Bakht Alruda, Ed-duim, Sudan.*
*[3]Department of Agricultural Engineering, College of Agricultural Studies, Sudan University of Science and Technology, Shambat, P.O. Box 71, Khartoum North, Sudan.*

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## ABSTRACT

Sixteen genotypes of rice (*Oryza sativa* L.) were evaluated during 2008 and 2009 growing seasons at two regions at the State of White Nile- Sudan (EDduim and Kosti) to assess stability of performance, and identify high yielding genotypes. The aim of the comparative study was to assess the performance of breeding lines developed for various ecosystems and to identify stable genotypes with wide adaptability. A randomized complete block design with three replications was used in each location. Combined analysis of variance revealed highly significant effects of locations, seasons, genotypes and their interactions for most of the studied traits. All the genotypes gave high grain yield which ranged from 2.17 to 4.03 t ha$^{-1}$ under irrigated conditions. Simple and combined analyses of variance indicated that genotypes differed significantly in grain yield, NERICA 4, NERICA 14, NERICA 15, YUNLU 33 and WAB-1-38-19-14-P2-HB were higher yielding genotypes giving 3.78, 4.03, 3.24, 3.55 and 3.51 t ha$^{-1}$ respectively. Due to the observed temporal and spatial variability multi-objective compromise programming technique is employed to screen these Rice (*Oryza sativa* L.) genotypes according to their vegetative and yield traits for purpose of selecting the most stable ones that suit irrigated farming conditions of the studied areas Ranking of alternatives was explored in reference to selection criteria

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**Corresponding author: Email: atifelsadig@yahoo.com;*

weights preferred by an agronomist, in comparison to equal weights. Two genotypes, NERICA 14 and YUNLU 33, were classified as high yielding and stable genotypes across environments (locations and years) because of their high grain yield and best performance of traits, with both a regression coefficient and multi-criteria analysis. These two genotypes could be used in the breeding program and/or may be released to farmers for cultivation in the White Nile State.

*Keywords: Rice; yield stability; variability; genotypes; multiple-objective optimization; multi criteria; compromise solutions, agronomic traits.*

## 1. INTRODUCTION

Rice (*Oryza sativa* L.) is considered as one of the most important crop for Asian and Middle East populations and is the main meal for 2.4 billion of world population. In Sudan rice is a promising and potential cereal crop in White Nile areas (Awok et al., 1996). Its production and average yield exhibits fluctuation mainly due to cultivation of low yielding and environment sensitive genotypes. Identification of genotypes that show minimum interaction with the environment or possess greater yield stability is an important consideration in areas where environmental fluctuations are considerable (Sedghi-azar et al., 2008). Stable performance is one of the most desirable properties of a genotype to be released as a variety for wide cultivation. Grain yield in rice is an expression of different yield components under given environmental conditions. Therefore, yield stability is not function of the genotype alone, but on interaction of genotype with the particular environment. The environmental fluctuations greatly influence the phenotypic expression of the genotypes in varying degrees and thus exhibit variability in adaptation across locations. In breeding programs and consideration of the amount of adaptability of crops in relation to different geographical conditions, have a special importance. Thus the genotype-environment interaction is of major concern to a plant breeder, because such interactions confine the selection of superior cultivars by altering their relative productiveness in different environments (Eaggles and Frey, 1977). Overall, adaptable varieties are those cultivars that can express stable genetic potential in different environmental conditions. Varieties in a series of environments have stable average yield are known to have vast adaptability. However, varieties, which show high yielding genetic potential only in desirable conditions but poor yielding potential in un-desirable conditions known as varieties with finite adaptability (Lin and Bins, 1991). To meet this goal, estimation of genotype × environment interaction is extremely imperative and is very important before releasing varieties. So, the present investigation was, therefore, undertaken to characterize the stability of 16 rice genotypes in respect of grain yield and growth characters and to identify the stable ones. Breeding genotypes that are adapted throughout a reasonable large geographical area and that show some degree of stability from year to year is a major problem facing plant breeders. As a result, several methods of measuring and describing genotypic response across environments have been developed and utilized. There are a number of statistical (Regression) and operation research (Compromise Programming) methods for consideration of genotype × environment interaction and its relationship with stability. Regression analysis of mean of each genotype on environmental index is an important statistical method of measuring a genotype's response to varying environmental conditions (Tesemma et al., 1998; Eberhart and Russell, 1966). Wricke's (1962) proposed the use of equivalence, the contribution of genotype to the genotype x environment interaction, as a measure of phenotypic stability. Similarly, deviation from regression ($S^2d$) has also been used as a measure of phenotypic stability (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966). Pinthus (1973) proposed the coefficient of determination ($R^2$), the portion of the total production variation of a given genotype that is explained by linear regression, as an index of production stability over environments. Moreover, a number of statistical methods have been proposed to measure the genotypic stability; however, no single method can adequately explain genotypes performance across environment (Abeysiriwardena et al., 1991; Lin et al., 1986; Lin and Binns, 1986; Becker and Leon, 1988). Compromise Programming (CP) defines the best solution as the one whose point is at the least distance from an ideal point (utopia) in the set of efficient solutions. The aim is to obtain a solution that is as close as possible to some ideal solution based on a parameter which reflects the attitude of the decision maker. The fact is Multi-criteria decision making (MCDM) is characterized by three major groups of techniques: Outranking techniques, Multi-attribute utility techniques and mathematical programming techniques (Goicoechea et al., 1982; and Srdjevic et al., 2004). The first technique requires pair-wise comparison among the existing alternatives. The second one relies on simple multiplicative models. However, compromise programming remains in the third category. The advantages and disadvantages of these models are the outranking technique seems not to be practical when the number of the alternatives is large (Because it utilizes the pair wise comparison technique). The second model has the disadvantage of not being appropriate for complex environmental systems analysis as it is a very simplistic model. On the other hand compromise programming is quite suitable for using in continuous contexts (Zeleny, 1982). This model targets answers by identifying those solutions which are closest to the ideal solution through measure which is referred to as the distance metric. The closest solution to the ideal is called the compromised solution. “In using CP and many other MCDM techniques to evaluate a set of potential alternatives a single optimal solution that equally satisfies all criteria is often infeasible. Instead of seeking a single optimal solution, a subset of non-inferior (non-dominated) solutions is sought. For each solution, which is outside the non-dominated subset but still within the feasible region, there is a non dominated solution for which all criteria are unchanged or improved and at least one that is strictly improved (Goicoechea et al., 1982). In Compromise Programming minimization of this closeness is a surrogate of the standard maximization of the criterion function. The distance measure used in CP is the family of Lp–metrics defined in especial way (Zeleny, 1982) and with a parameter p to implicitly express the DM’s attitude to balance criteria ($p=1$), to accept decreasing marginal utility ($p>1$), or to search for absolutely dominant solution ($p = \infty$). The most common value is $p=2$. Whichever parameter value is used, an alternative with minimum Lp–metric is considered as the best (Srdjevic et al., 2004). For this purpose, multi-location trials, over a number of years are conducted. Testing genotypes over different location differing in unpredictable environmental variation is a suitable approach for selecting stable genotypes (Eberhart and Russell, 1966). Plaisted and Paterson (1959) presented a method to characterize the stability of yield performance when several genotypes are tested at a number of locations within one year. The genotypes with the smallest mean value would be the one that contributed the least to genotype x location interactions and thus would be considered the most stable genotypes in the test. Rice varieties responses in different locations and years have been considered by a lot of workers in order to determine yield adaptability and stability (Ram et al., 1978; Mahajan & Prasad, 1986; Moeljopawiro, 1989; Gravoic et al., 1991). In order to determine adaptability and stability of rice cultivars, Dorosti et al., (1997) considered 11 rice cultivars in three environments from 1993 to 1995. Simple analysis of variance of yield showed significant variations among varieties. In combined analysis, year × location and treatment × year × location interactions were significant. One of the most frequently used stability measures is based on a regression model. This measure was first proposed by Yates and Cochran, (1938). However, it was developed by Finlay and Wilkinson, (1963) to describe the adaptation of individual varieties to changing environment and while Eberhart and Russell, (1966), used b-value as measures of environmental response and deviations from regression ($S^2d$) as measures of stability. Other indices proposed for measuring response of cultivars and stability of production in variable environments included the multiple coefficient of determination, $R^2$ (Pinthus, 1973). This $R^2$ measures the proportion of a variety's production variation that is due to linear regression. Results of stability analysis based on Eberhart and Russell (1966) showed that line 211 with regression coefficient of 0.22 (having significant difference with unit) had more than medium stability and suitable for environment with low productivity. Other genotypes like lines 222 (Khazar), 414, 415 and 418 had general adaptability and stability but producing inadequate yield. Moreover, their reaction to environmental index (improvement of growth conditions) showed deviations from regression line. Several of these statistics have been summarized and compared by Lin et al. (1986) who pointed out that stability statistics fall into four groups depending on whether they are based on the deviation from the average genotype effect or on the genotype x environment (GxE) term and whether or not they incorporate a regression model on an environment index. A genotype may be considered stable if its environmental variance is small, if its response to environment is parallel to the means response of all genotypes in the trial, or if the residual mean square from a regression model on environmental index is small. The objectives of the current study were: to evaluate the performance of Rice genotypes for various ecosystems and to identify stable genotypes under diverse environments (locations and years); and to employ three stability regression indices (to identify high yielding and stable genotypes) and multi-criteria evaluation technique (to identify the most stable genotype with respect to overall index for both yield and yield components) for purpose of recommending the most preferred genotype to the farmers in the White Nile State, Sudan.

## 2. MATERIALS AND METHODS

### 2.1 Description of the Experiment

Sixteen rice genotypes were studied in a randomized complete block design with three replicates during 2008 and 2009 seasons at two locations in the White Nile State, Sudan (viz. Ed-duim, Faculty of Agriculture and Natural Resources farm, University of Bakht Alruda long. 32º20'E, lat. 13º39' N and 380 m s l and Kosti Research Station farm of the Agricultural Research Corporation long. 32º46' lat. 13º6'N) to evaluate grain yield stability of some exotic rice genotypes. The experimental material comprised sixteen exotic rice genotypes seven genotypes were obtained from the Republic of Côte d'Ivoire**,** six genotypes from China and three genotypes from the Philippines (Table 1). Seeds were sown directly in the field on the second week of July of each year. Phosphorus fertilizer in the form of triple super phosphate ($P_2O_5$) was applied as a basal dose before sowing at the rate of 43 kg ha$^{-1}$. Nitrogen, in the form of urea (46% N), was applied in two equal split doses, one after three weeks from sowing and the second after one month from the first one at the rate of 86 kg N ha$^{-1}$ in each location. Standard cultural practices (including weeding, irrigation and plant protection) recommended by the Agricultural Research Corporation (ARC) in Sudan were followed in all the trials to raise the crop successfully.

WARDA=West African Rice Development Association, YAAS=Yunnan Academy of Agricultural Science, IRRI= International Rice Research Institute. The plot size was 8 m$^2$ with inter-row and intra-row spacing of 0.20 x 0.02 m. Five plants were selected randomly from each plot, and data on agronomic traits were measured for plant height (cm), days from sowing to 50% flowering, days from sowing to the time when 50% of the panicles reached full maturity (panicles color turned yellow), average panicle length (cm), number of tillers per plant, number of grains/panicle, number of filled grains/panicle, percentage of empty grains/panicle, 1000-grain weight, number of panicles/m$^2$ and grain yield (t/ha).

**Table 1. Rice genotypes, their institute and origin**

| Genotypes | Institute | Origin |
|---|---|---|
| NERICA 2 | WARDA | Cote d'Ivoire |
| NERICA 4 | WARDA | Cote d'Ivoire |
| NERICA 5 | WARDA | Cote d'Ivoire |
| NERICA 12 | WARDA | Cote d'Ivoire |
| NERICA 14 | WARDA | Cote d'Ivoire |
| NERICA 15 | WARDA | Cote d'Ivoire |
| NERICA 17 | WARDA | Cote d'Ivoire |
| YUNLU 22 | YAAS | China |
| YUNLU 24 | YAAS | China |
| YUNLU 26 | YAAS | China |
| YUNLU 30 | YAAS | China |
| YUNLU 33 | YAAS | China |
| YUNLU 34 | YAAS | China |
| WAB-1-38-19-14-P2-HB | IRRI | Philippines |
| WAB880-1-38-19-8 | IRRI | Philippines |
| WAB891SG12 | IRRI | Philippines |

## 2.2 Data Analysis

Statistical analysis was conducted by using the computer software SAS (1997). The data were analyzed location-wise and then combined over locations. Data analysis was made using analysis of variance by employing SAS computer program and means were separated using Duncan's Multiple Range Test at 5% level of significance Gomez and Gomez, (1984). Stability parameters (biand $S^2$d1) were estimated according to Eberhart and Russell, (1966).

## 2.3 Statistical Analysis

Analysis of variance was employed for analysis of yield data assuming random environment (locations and years) and fixed genotype according to the procedure described by Gomez and Gomez (1984) to determine the significance of genotypes, environments and genotype x environments (G x E) interactions. Separate and combined analysis of the collected data analysis was conducted using the method proposed by Finlay and Wilkinson, (1963) and Eberhart and Russell, (1966). Consequently, mean yield (x) and coefficient of regression (bi-value) were used as measures of yield response of genotypes in varying environment and adaptation patterns. To arrive to this aim, three stability parameters were used to estimate the grain yield stability. These include:

1) Stability parameter type one (Finlay and Wilkinson, 1963): which indicated that the genotype with maximum yield potential over environment, regression coefficient equal to one would best able;

2) Stability parameter type two (Eberhart and Russell, 1966): It is used for G x E interaction was the mean square deviation from regression ($S^2d$). Eberhart and Russell (1966) emphasized that both linear (bi) and non-linear ($S^2d$) components of G x E interactions are necessary for judging the stability of a genotype. A regression coefficient (bi) approximating 1.0 coupled with $S^2d$ of zero indicates average stability. Regression values above 1.0 describe genotypes with higher sensitivity to environmental change (below average stability) and greater specificity of adaptability to high yielding environments. A regression coefficient below 1.0 provides a measurement of greater resistance to environmental change (above average stability) and thus increases the specificity of adaptability to low yielding environments;

3) Stability parameter type three (Wricke's, 1962) for environment interaction: This approach is based on estimating the eco valence (*Wi*) for each genotype to measure the impact of environment on each genotype. As such, the ideal genotype is taken as the one that has the highest average grain yield, a bi-value of approximately one and both *Wi* and $S^2d$ values close to zero. This is derived by measuring the deviation of the individual genotype from the location means of all genotypes in the test. With this statistic, the genotype that is most stable is the one that revealed smaller values of the statistic.

## 2.4 Multi-Criteria Analysis

Compromise programming was used to choose the optimum genotypes from a set of efficient ones as proposed by Zeleny (1982). CP starts by establishing the ideal point whose coordinates are given by the optimum values of the various objectives of the decision maker. The ideal point is usually infeasible. If it is feasible then there is no conflict among objectives. When the ideal point is infeasible the optimum element or compromise solutions is given by the efficient solution that is closer to the ideal point. Thus, the degree of closeness as relative deviation d1 between the jth objective and its ideal value is defined by:

$$dj = (Z^*j - Zj\ (X)) / (Z^*j - Z^*j\ ) \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where Z*j and Z*j were the ideal and anti-ideal values for the jth objective. Relative rather than absolute deviations had to be used, as the units of measurement of the different objectives were not the same. X is a vector of the decision variables and Zj (x) is the jth objective function ought to be optimized. In order to measure the distances between each solution and the ideal point the following distance function was used.

$$KLP\ (\infty, K) = [\Sigma\ \{\alpha\ j, d\ j\}\ 1/\ p] \ldots\ldots\ldots\ldots\ldots\ldots \ (2)\ j=1$$

Where, P was taken as 1 (L1) and ∞ (L∞) representing 'longest' and 'shortest' distances in the geometric sense. The parameter P in the above expression weights the deviations according to their magnitudes. Greater weight is given to the longest deviations as the magnitude of P increases. Thus, with P = ∞ the maximum of the individual deviation is minimized α j j represents the weights to d j signifying the importance of the discrepancy between the jth objective and its ideal value. In the study two sets of α j were considered to obtain the different compromise solutions under the assumptions of varying weights for the discrepancies (equal weights and weights according to view of the agronomist). The magnitude of K in the present case was nine i.e., the number of objectives considered for optimization. Lp representing the longest distance geometrically was minimized by using the following linear programming problem for obtaining the best compromise farm plan.

$$\text{Min } Lp = (\alpha\ 1\ (Z^*j - Zj\ (X))\ /\ (Z^*j - Z^*j)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (3)$$

$$X \in F\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (4)$$

Where:
F is the set of all feasible farm plans, and X is a vector of the decision variables.

$X \in F$ thus denotes the linear constraints and non-negatively restrictions component of the standard LP problem. For $L = \infty$, where the maximum of the individual deviations is minimized, the best compromise genotype was obtained by solving the linear problems. For purpose of multi-criteria analysis payoff matrix of the measured traits for each genotype is combined for two seasons and shown in Table 2.

Ten procedural steps within the agronomic practices and decision-making framework can be identified taking into consideration crop yield and yield components:

1. Selection of an approach and creation of framework for multi-criteria analysis (MCA) and evaluation of decision elements.
2. Defining sustainability criteria and setting objectives.
3. Formulation of genotypes or/and management alternatives.
4. Integrating output from spatial analysis using field trials and valuation of yield and yield components for multi-criteria evaluation.
5. Decomposition of sustainability criteria on a hierarchical basis.
6. Development of pay-off (decision) matrix.
7. Set up maximum and minimum values for each criterion (the ideal points).
8. Decide on target of optimization for objective function.
9. Assigning weights to criteria for each decision-maker.
10. Applying MCA and deriving decisions by using selected multi-criteria decision making tools (Compromise Programming; CP).
11. Estimate the Compromise distances for each alternative.
12. Rank alternative genotypes.

## 3. RESULTS AND DISCUSSION

### 3.1 Results of Multi Criteria Analysis

The means of yield and growth traits of Rice genotypes evaluated during the Season 2008 and 2009 respectively are given in Table 2. Data of Table 2 is used for multi criteria analysis and the outcome is given in Table 3.

Table 3 indicates the status of the objective functions (max. or min.) for each trait as specified by a field agronomist through direct evaluation using the range of 0 to 1.0.

The pay off matrix of Table 4 shows the scores achieved by each Rice genotype for means yield, and growth traits evaluated during the Seasons 2008 and 2009. The criteria vectors of maximum (best) and minimum (worst) values and criteria weight set for each genotype (treatment or alternative) are also given in Table 4.

**Table 2. Combined means for yield and growth traits of Rice genotypes evaluated during the season 2008 and 2009, respectively**

| Genotypes | Plant height (cm) | Tiller/ plant | Length (cm) | Number grains/ panicle | Number filled grains/ panicle | Unfilled grains % | Number panicle /panicle/m$^2$ | Days to 50% flowering | Days to 50% maturity |
|---|---|---|---|---|---|---|---|---|---|
| NERICA 2 | 70.4 | 5.675 | 17.73 | 69.5 | 41.025 | 39.35 | 367.88 | 76.3 | 102.5 |
| NERICA 4 | 73.4 | 4.575 | 19.15 | 76.425 | 53.75 | 30.075 | 399.3 | 80.1 | 101.15 |
| NERICA 5 | 66.2 | 6.225 | 17.9 | 70.75 | 43.425 | 44 | 363.65 | 71.15 | 104.8 |
| NERICA 12 | 81.3 | 4.8 | 19.65 | 75.6 | 52.175 | 31.25 | 356.63 | 81.5 | 101.65 |
| NERICA 14 | 72.7 | 5.575 | 18.83 | 75.4 | 55.15 | 29.575 | 364.95 | 67.3 | 89.1 |
| NERICA 15 | 81.6 | 4.675 | 17.83 | 74.55 | 5095 | 34.6 | 303.7 | 84 | 112.15 |
| NERICA 17 | 72.5 | 4.725 | 17.65 | 66.35 | 41.825 | 35.825 | 392.45 | 82.45 | 104.6 |
| NERICA 22 | 80.3 | 5 | 17.18 | 63.2 | 40.675 | 36.5 | 383.7 | 81.8 | 102.65 |
| NERICA 24 | 70.3 | 4.55 | 17.15 | 71.75 | 45.075 | 37.25 | 358.15 | 82.3 | 113.3 |
| NERICA 26 | 78 | 4.4 | 17.48 | 70.8 | 44.4 | 35.85 | 351.98 | 80.95 | 103.8 |
| NERICA 30 | 79.4 | 5.15 | 16.08 | 82.1 | 58.175 | 31.425 | 349.13 | 78.15 | 114.8 |
| NERICA 33 | 83.6 | 5.4 | 18.08 | 74.65 | 49.475 | 37.4 | 361.5 | 82.3 | 99 |
| NERICA 34 | 79.4 | 4.675 | 18.4 | 74.325 | 53.15 | 36.85 | 349.55 | 83.65 | 115.3 |
| WAB880-1 38-19-8 | 65.8 | 4.75 | 16.9 | 72.825 | 43.75 | 38.425 | 347.45 | 83.65 | 109.65 |
| WAB891SG12 | 74.8 | 5.35 | 16.9 | 69.075 | 43.25 | 41.575 | 344.55 | 81.8 | 110.8 |
| WAB-1-38-19-14-P2-HB | 69.6 | 5.475 | 17.93 | 75.9 | 51.925 | 37.025 | 365.63 | 77.8 | 97.3 |
| Max-Min | 83.6 | 6.225 | 19.65 | 82.1 | 58.175 | 44 | 399.3 | 84 | 120.65 |
| Min | 65.8 | 4.4 | 16.08 | 63.2 | 40.675 | 29.575 | 303.7 | 67.3 | 89.1 |
| Max-Min | 17.8 | 1.825 | 3.575 | 18.9 | 17.5 | 14.425 | 95.6 | 16.7 | 31.55 |

**Table 3. Vectors of maximum (best) and minimum (worst) values and four sets of criterion weights**

| **Traits** | **Maximum** | **Minimum** | **Expert criteria weights(α)** | |
|---|---|---|---|---|
| Plant height(cm) | 226 | 149 | 0.11 | 0.07 |
| Tillers/plant | 64 | 51 | 0.11 | 0.1 |
| Length panicle (cm) | 7 | 6 | 0.11 | .01 |
| No. filled Grains/panicle | 81 | 57 | 0.11 | 0.2 |
| No. panicle/m$^2$ | 20 | 15 | 0.11 | 0.2 |
| % unfilled Grains/panicle | 487 | 0 | 0.11 | 0.03 |
| No. panicle/m$^2$ | 15 | 342 | 0.11 | 0.2 |
| Days to 50% Flowering | 15 | 14 | 0.11 | 0.05 |
| Days to 50% Maturity | 15 | 13 | 0.11 | 0.05 |

To solve the multi-criterion problem using compromise programming algorithm the values of vectors of ideal points, max and worst values, status of the objective functions, is determined for the dual cases of equal weights and variable weights (agronomist preferences). Consequently, this enables determination of ideal distance (Lp) for each genotype.

## 3.2 Results of Combined Analysis of Variance

Table 6, which is based on data of Table 2, shows the mean squares for seasons, locations, genotypes and their interactions. It indicates that the mean squares due to seasons were highly significant ($P \leq 0.01$) for all studied traits except grain weight which reflects genotypic variability for both seasons. It can be observed that there is highly significant spatial effect for most of the studied traits with the exception of grain yield. In par titular grain yield varied only at $P \leq 0.05$, while plant height, number of filled grains/panicle and grain weight shows no significant effects. The observed spatial variation in means of grain yield and other traits express location variations in growth parameters during the study test period. It's evident from Table 6 that there is significant genotypic variation for most traits studied except the number of tillers/plant, number of grains/panicle, percentage of empty grains/panicle and number of panicles/m$^2$. This wide variation between genotypes made selection of the most suitable one a difficult task.

Analysis of variance for grain yield combined over seasons and locations for 16 rice genotypes, given in Table 7, shows that means of genotype yield ranged from 2.17 to 4.03 ton ha$^{-1}$ 23. The highest yielding genotypes were NERICA 14, NERICA 4, YUNLU 33 and WAB-1-38-19-14-P2-HB. Nine genotypes yielded between 3.21 and 4.03 ton ha$^{-1}$, six genotypes between 2.50 and 3.10 ton ha$^{-1}$ 25 and one genotype less than 2.18 ton ha$^{-1}$ 26.

**Table 4. Pay off matrix for Scores achieved by each Rice genotype for means yield, growth traits and the vectors of maximum (best) and minimum (worst) values evaluated during the seasons 2008 and 2009**

| **Genotypes** | **Plant height (cm)** | **Tiller/ plant** | **Length (cm)** | **Number grains/ panicle** | **Number filled grains/ panicle** | **Unfilled grains /panicle %** | **Number panicle /m$^2$** | **Days to 50% flowering** | **Days to 50% maturity** |
|---|---|---|---|---|---|---|---|---|---|
| **Max/Min** | **Min.** | **Max.** | **Max.** | **Max.** | **Max.** | **Min.** | **Max.** | **Min.** | **Min.** |
| NERICA 2 | 0.259 | 0.301 | 0.538 | 0.667 | 0.980 | 0.678 | 0.329 | 0.539 | 0.425 |
| NERICA 4 | 0.427 | 0.904 | 0.140 | 0.300 | 0.253 | 0.035 | 0.000 | 0.766 | 0.382 |
| NERICA 5 | 0.018 | 0.000 | 0.490 | 0.636 | 0.843 | 1.000 | 0.373 | 0.231 | 0.498 |
| NERICA 12 | 0.873 | 0.731 | 0.000 | 0.344 | 0.343 | 0.116 | 0.446 | 0.850 | 0.398 |
| NERICA 14 | 0.386 | 0.356 | 0.231 | 0.354 | 0.173 | 0.000 | 0.359 | 0.000 | 0.00 |
| NERICA 15 | 0.887 | 0.849 | 0.510 | 0.399 | 0.413 | 0.348 | 1.000 | 1.000 | 0.731 |
| NERICA 17 | 0.376 | 0.822 | 0.559 | 0.833 | 0.934 | 0.433 | 0.072 | 0.907 | 0.491 |
| NERICA 22 | 0.817 | 0.671 | 0.692 | 1.000 | 1.000 | 0.480 | 0.163 | 0.868 | 1.000 |
| NERICA 24 | 0.254 | 0.918 | 0.699 | 0.548 | 0.749 | 0.532 | 0.430 | 0.898 | 0.767 |
| NERICA 26 | 0.685 | 1.000 | 0.608 | 0.598 | 0.787 | 0.435 | 0.495 | 0.817 | 0.466 |
| NERICA 30 | 0.762 | 0.589 | 1.000 | 0.000 | 0.000 | 0.128 | 0.525 | 0.650 | 0.815 |
| NERICA 33 | 1.000 | 0.452 | 0.441 | 0.394 | 0.497 | 0.542 | 0.395 | 0.898 | 0.314 |
| NERICA 34 | 0.766 | 0.849 | 0.350 | 0.411 | 0.287 | 0.504 | 0.520 | 0.979 | 0.830 |
| WAB880-1 38-19-8 | 0.000 | 0.808 | 0.769 | 0.491 | 0.824 | 0.614 | 0.542 | 0.979 | 0.651 |
| WAB891SG12 | 0.503 | 0.479 | 0.769 | 0.689 | 0.853 | 0.832 | 0.573 | 0.868 | 0.688 |
| WAB-1-38-19-14-P2-HB | 0.211 | 0.411 | 0.483 | 0.328 | 0.375 | 0.516 | 0.352 | 0.629 | 0.260 |
| Best | 83.6 | 6.225 | 19.65 | 82.1 | 58.175 | 44 | 399.3 | 84 | 120.65 |
| Worst | 65.8 | 4.4 | 16.08 | 63.2 | 40.675 | 29.575 | 303.7 | 67.3 | 89.1 |
| Max-Min | 17.8 | 1.825 | 3.575 | 18.9 | 17.5 | 14.425 | 95.6 | 16.7 | 31.55 |

**Table 5a. Compromise distance (Lp) calculated for each Rice genotype from means of scores of yield, growth traits for seasons 2008 and 2009 and the case of equal weight**

| **Equal weight (wi)**<br>**Genotypes** | **0.11**<br>**Plant height (cm)** | **0.11**<br>**Tiller/ plant** | **0.11**<br>**Length (cm)** | **0.11**<br>**Number grains/ panicle** | **0.11**<br>**Number filled grains/ panicle** | **0.11**<br>**Percentage of unfilled Grains/panicle** | **0.11**<br>**Number panicle /panicle /m$^2$** | **0.11**<br>**Days to 50% flowering** | **0.11**<br>**Days to 50% maturity** |
|---|---|---|---|---|---|---|---|---|---|
| **Max/Min** | **Min.** | **Max.** | **Max.** | **Max.** | **Max.** | **Min.** | **Max.** | **Min.** | **Min.** |
| NERICA 2 | 0.029 | 0.033 | 0.060 | 0.074 | 0.109 | 0.075 | 0.037 | 0.030 | 0.047 |
| NERICA 4 | 0.047 | 0.100 | 0.016 | 0.033 | 0.028 | 0.004 | 0.000 | 0.058 | 0.042 |
| NERICA 5 | 0.002 | 0.087 | 0.054 | 0.071 | 0.094 | 0.111 | 0.041 | 0.026 | 0.055 |
| NERICA 12 | 0.097 | 0.040 | 0.000 | 0.038 | 0.038 | 0.13 | 0.050 | 0.094 | 0.044 |
| NERICA 14 | 0.043 | 0.094 | 0.026 | 0.039 | 0.019 | 0.000 | 0.040 | 0.000 | 0.000 |
| NERICA 15 | 0.099 | 0.091 | 0.057 | 0.044 | 0.038 | 0.039 | 0.111 | 0.111 | 0.081 |
| NERICA 17 | 0.042 | 0.075 | 0.062 | 0.093 | 0.019 | 0.048 | 0.008 | 0.101 | 0.055 |
| NERICA 22 | 0.091 | 0.102 | 0.077 | 0.111 | 0.046 | 0.053 | 0.018 | 0.096 | 0.111 |
| NERICA 24 | 0.028 | 0.111 | 0.078 | 0.061 | 0.104 | 0.059 | 0.048 | 0.100 | 0.085 |
| NERICA 26 | 0.076 | 0.065 | 0.068 | 0.066 | 0.111 | 0.048 | 0.055 | 0.091 | 0.052 |
| NERICA 30 | 0.085 | 0.050 | 0.111 | 0.000 | 0.083 | 0.014 | 0.058 | 0.072 | 0.091 |
| NERICA 33 | 0.111 | 0.094 | 0.049 | 0.044 | 0.087 | 0.060 | 0.044 | 0.100 | 0.035 |
| NERICA 34 | 0.085 | 0.090 | 0.039 | 0.046 | 0.000 | 0.056 | 0.058 | 0.109 | 0.092 |
| WAB880-1 38-19-8 | 0.000 | 0.053 | 0.085 | 0.055 | 0.055 | 0068 | 0.030 | 0.109 | 0.072 |
| WAB891SG12 | 0.056 | 0.053 | 0.085 | 0.077 | 0.095 | 0.092 | 0.064 | 0.096 | 0.076 |
| WAB-1-38-19-14-P2-HB | 0.023 | 0.046 | 0.054 | 0.036 | 0.040 | 0.057 | 0.039 | 0.070 | 0.029 |

**Table 5b. Compromise distance (Lp) calculated for each Rice genotype from means of scores of yield, growth traits for seasons 2008 and 2009 and for the case of variable weights as evaluated by field agronomist**

| **Agronomist weight (wi)** | **0.07** | **0.1** | **0.1** | **0.2** | **0.2** | **0.3** | **0.2** | **0.5** | **0.05** | **1** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Genotypes** | **Plant height (cm)** | **Tiller/ plant** | **Length (cm)** | **Number grains/ panicle** | **Number filled grains/ panicle** | **Percentage of unfilled Grains/ panicle** | **Number panicle /panicle /m2** | **Days to 50% flowering** | **Days to 50% maturity** | **Compromise distance** |
| **Max/Min** | **Min** | **Max** | **Max** | **Max** | **Max** | **Min** | **Max** | **Min** | **Min** | |
| NERICA 2 | 0.018 | 0.030 | 0.054 | 0.133 | 0.196 | 0.020 | 0.066 | 0.027 | 0.021 | 0.566 |
| NERICA 4 | 0.030 | 0.090 | 0.014 | 0.060 | 0.051 | 0.001 | 0.000 | 0.038 | 0.019 | 0.303 |
| NERICA 5 | 0.001 | 0.000 | 0049 | 0.127 | 0.169 | 0.030 | 0.075 | 0.012 | 0.025 | 0.487 |
| NERICA 12 | 0.061 | 0.078 | 0.000 | 0.069 | 0.069 | 0.003 | 0.089 | 0.043 | 0.020 | 0.432 |
| NERICA 14 | 0.027 | 0.036 | 0.023 | 0.071 | 0.035 | 0.000 | 0.072 | 0.000 | 0.000 | 0.263 |
| NERICA 15 | 0.062 | 0.085 | 0.051 | 0.080 | 0.083 | 0.010 | 0.200 | 0.050 | 0.037 | 0.658 |
| NERICA 17 | 0.026 | 0.082 | 0.056 | 0.176 | 0.187 | 0.013 | 0.014 | 0.045 | 0.025 | 0.615 |
| NERICA 22 | 0.057 | 0.067 | 0.069 | 0.200 | 0.200 | 0.014 | 0.033 | 0.043 | 0.050 | 0.734 |
| NERICA 24 | 0.018 | 0.092 | 0.070 | 0.110 | 0.150 | 0.016 | 0.086 | 0.045 | 0.038 | 0.624 |
| NERICA 26 | 0.048 | 0.100 | 0.061 | 0.120 | 0.157 | 0.013 | 0.099 | 0.041 | 0.023 | 0.662 |
| NERICA 30 | 0.053 | 0.059 | 0.100 | 0.000 | 0.000 | 0.004 | 0.105 | 0.032 | 0.041 | 0.394 |
| NERICA 33 | 0.070 | 0.045 | 0.044 | 0.079 | 0.099 | 0.016 | 0.079 | 0.045 | 0.016 | 0.493 |
| NERICA 34 | 0.054 | 0.085 | 0.035 | 0.082 | 0.057 | 0.015 | 0.104 | 0.049 | 0.042 | 0.523 |
| WAB880-1 38-19-8 | 0.000 | 0.081 | 0.077 | 0.0098 | 0.165 | 0.018 | 0.108 | 0.049 | 0.033 | 0.629 |
| WAB891SG12 | 0.035 | 0.048 | 0.077 | 0.138 | 0171 | 0.025 | 0.115 | 0.043 | 0.034 | 0.686 |
| WAB-1-38-19-14-P2-HB | 0.015 | 0.041 | 0.048 | 0.066 | 0.071 | 0.015 | 0.070 | 0.031 | 0.013 | 0.372 |

**Table 6. Analysis of variance for grain yield and its components combined over seasons and locations for rice genotypes**

| Traits | Season (S) | Location (L) | Genotype (G) |
|---|---|---|---|
| PH | 19683.00** | 40.33 | 314.44** |
| NTP | 82.68** | 225.33** | 3.20 |
| PL | 1205.00** | 109.50** | 9.72** |
| NGP | 100467.00** | 3485.02** | 237.88 |
| NFG | 79096.92** | 27.75 | 389.16* |
| PEG | 14093.88** | 1734.00** | 188.62 |
| NP/m$^2$ | 256741.88** | 428935.54** | 6334.30 |
| TGW | 3.52 | 3.52 | 79.29** |
| GY | 57.75** | 5.23* | 2.74** |

*PH =Plant height (cm), NTP=Number of tillers/plant, PL=Panicle length (cm), NGP=Number of grains/panicle, NFG=Number of filled grains/panicle, PEG=Percentage of empty grains/panicle, NT/m$^2$=Number of Panicles/m$^2$, TGW=1000-grains weight, GY=Grain yield (t/ha).*
**, ** Significant at the 0.05 and 0.01 probability levels, respectively.*

**Table 7. Ranking for grain yield combined over seasons and locations 33 for 16 rice genotypes**

| Genotype | Mean | Yield rank |
|---|---|---|
| NERICA 2 | 2. 50 | 15 |
| NERICA 4 | 3.78 | 2 |
| NERICA 5 | 2.17 | 16 |
| NERICA 12 | 3.10 | 11 |
| NERICA 14 | 4.03 | 1 |
| NERICA 15 | 3.24 | 8 |
| NERICA 17 | 2.50 | 14 |
| YUNLU 22 | 3.06 | 12 |
| YUNLU 24 | 3.30 | 6 |
| YUNLU 26 | 3.10 | 10 |
| YUNLU 30 | 3.21 | 9 |
| YUNLU 33 | 3.55 | 3 |
| YUNLU 34 | 3.30 | 7 |
| WAB880-1-38-19-8 | 3.33 | 4 |
| WAB891SG12 | 2.87 | 5 |
| WAB-1-38-19-14- P2-HB | 3.51 | 13 |

## 3.3 Analysis of Genotypes Performance for Location

For the interactions of Season x location, there is a highly significant differences for all of the traits, except number of tillers/plant, panicle length and number of grains/panicle (Table 8). In contrast the genotype by seasons (Genotype x Season) Interaction was not significant for all the traits, with the exception of 1000 grain weight. As such the Characters that showed no significance for Genotype x Season effect indicated stable performance for both seasons similar findings were reported by Biswas et al. (2011). The test of interaction of Genotype x Location demonstrates the temporal response of the Genotype and the need for testing such response for a number of seasons. As given in table 6 the mean squares due to interaction of Genotype by Location were significant ($P \leq 0.01$) only for the number of grains per panicle, number of filled grains/panicle and grain yield, while for other traits it was not significant. This result is in agreement with Goncalves et al., (2003) and demonstrates the challenges encountered by breeders in selecting new genotypes for release to perform well under variable environmental conditions. It is also important for releasing the genotype that shows sustainable performance it is essential to assess the cross interaction of the three parameters Season x Location x Genotype (Reddy et al., 1998). To evaluate this end the test of the mean squares differences due to Season x Location x Genotype interactions was found to be significant only for the number of Grains/panicle and highly significant for grain yield, while the differences in the remaining traits were not significant. The inconsistency of genotypes and yield variability calls for in depth analysis of stability of performance and need to ascertain the relative impacts of each one of the studied traits and their overall crop performance. This variability among the locations may be attributed to the differences in soil type, temperature and rainfall during the growing season, since the genotypes were evaluated for two years. Also, the significant genotype x location interaction caused a difficulty in identifying superior yielding rice genotypes. Variability of rice genotypes across different Environment was stated by many investigators Honernejad et al., 2000; Hague et al. 1991; Gueye and Becker, 2011; Natarajan et al., 2005; Akhter et al., 2010; Selvaraj et al., 2011.

**Table 8. Analysis of variance for grain yield and its components combined for interaction of genotypes, locations and locations**

| **Traits** | **S x L** | **G x S** | **G x L** | **S x L x G** |
|---|---|---|---|---|
| PH | 5250.08** | 114.66 | 40.75 | 80.37 |
| NTP | 4.08 | 2.18 | 1.39 | 1.85 |
| PL | 0.04 | 4.81 | 3.05 | 2.36 |
| NGP | 0.75 | 384.04 | 530.38* | 518.62* |
| NFG | 3291.79** | 280.09 | 329.96* | 293.57 |
| PEG | 4651.17** | 143.50 | 100.48 | 133.99 |
| NP/m$^2$ | 565393.54** | 7078.15 | 8550.43 | 1632.18 |
| TGW | 229.68** | 19.78* | 12.06 | 9.29 |
| GY | 178.83** | 1.57 | 2.06* | 2.86** |

*PH =Plant height (cm), NTP=Number of tillers/plant, PL=Panicle length (cm), NGP=Number of grains/panicle, NFG=Number of filled grains/panicle, PEG=Percentage of empty grains/panic le, NT/m$^2$=Number of Panicles/m$^2$, TG W=1000-grains weight, GY=Grain yield (t/ha).*
**, **Significant at the 0.05 and 0.01 probability levels, respectively.*

## 3.4 Genotypes Yield Stability Analysis for Environment

The three yield stability indices were analyzed to assess variability of genotypes due to both location and environment as follows:

1. Environmental Stability type one: Table 9 indicates that, the regression of varietal average yield on the environment index of Finlay and Wilkinson, (1963) resulted in regression coefficients (bi values) ranging from 0.27 (NERICA 5) to 1.60 (YUNLU 34) for grain yield. This large variation in regression coefficients indicates different responses of genotypes to environmental changes. Also, these large variations in bi-values give the breeder an advantage to select genotypes for both adverse and favorable environments. Analysis according to Finlay and Wilkinson, (1963) model

showed that, the genotypes NERICA 14 and YU NLU 33 had maximum grain yields and regression coefficients close to one (bi-value of 0.80 and 0.9 4, respectively) and they were considered as stable genotypes. While genotypes NERICA 4 and W AB-1-38-19-14-P2-HB also had high grain yields but their regression coefficients were greater than one (1.4 for both) and then considered as unstable genotypes (Table 9).

**Table 9. Mean yield of the Rice genotypes and their stability indices**

| **Genotype** | **Location** | | **Environment** | | **Environment** |
|---|---|---|---|---|---|
| | **Eberhart and Russell** | | **Finlay-Wilkinson** | | **Wrike's (1962)** |
| | **bi** | **s$^2$d** | **bi** | **s$^2$d** | **wi** |
| NERICA 2 | 0.7 | 1.61 | 0.73 | 0.39 | 0.69 |
| NERICA 4 | 1.4 | 1.48 | 1.38 | 0.93 | 2.46 |
| NERICA 5 | 0.3 | 2.05 | 0.27 | 0.87 | 4.21 |
| NERICA 12 | -0.4 | 6.84 | -0.36 | 0.61 | 10.11 |
| NERICA 14 | 0.8 | 7.61 | 0.80 | 0.61 | 0.95 |
| NERICA 15 | 1.2 | 1.58 | 1.16 | 0.30 | 0.31 |
| NERICA 17 | 0.8 | 1.28 | 0.80 | 0.25 | 0.31 |
| YUNLU 22 | 1.4 | 0.96 | 1.37 | 0.29 | 0.87 |
| YUNLU 24 | 1.5 | 1.43 | 1.51 | 0.57 | 1.95 |
| YUNLU 26 | 1.3 | 1.53 | 1.33 | 1.10 | 3.0 |
| YUNLU 30 | 0.6 | 4.63 | 0.62 | 0.66 | 1.61 |
| YUNLU 33 | 0.9 | 4.19 | 0.94 | 0.69 | 0.94 |
| YUNLU 34 | 1.6 | 2.08 | 1.60 | 0.25 | 1.96 |
| WAB880-1-38-19-8 | 1.3 | 0.34 | 1.31 | 1.06 | 2.76 |
| WAB891SG12 | 1.1 | 0.52 | 1.11 | 0.16 | 0.11 |
| WAB-1-38-19-14-P2-HB | 1.4 | 0.43 | 1.44 | 0.20 | 1.07 |

*bi = Regression coefficient, S297 d= Deviation from regression, Wi= eco-valence.*

2. Environmental Stability type two: The stable genotype, as proposed by Eberhart and Russell (1966), indicate that the genotype NERICA 4 and YUNLU 33 gave the highest yield over the grand mean with respective regression coefficients of 0.80 and 0.94, respectively, 82 which were not significantly different from regression and deviation from regression coefficient value near to zero. These findings indicated that the two genotypes were high yielders as well as stable over environments (average stability). The genotype WAB-1-38-19-14-P2-HB had fourth best yield after NERICA 14, NERICA 4 and YUNLU 33 and proved to have below average stability (responsive to high yielding environments), as its regression coefficient (bi) is above one (1.44) and have also small deviation from regression (S$^2$d=0.43). Also, the genotype NERICA 4 showed high yield (3.78 t ha$^{-1}$88 ) and bi-value above one (1.38) and high deviation from regression (S$^2$d=1.48) indicating that its Performance was relatively better in high yielding environments (below average stability). In reference to high the grain yield obtained by the sixteen rice genotypes (ranged from 2.17 to 4.03 tonh$^{-1}$) under the White Nile areas, the genotype WAB891SG12 had a mean yield of 2.87 ton h$^{-1}$92, with bi-value near to one (1.11) and low deviation from regression (0.52) indicating a relatively Stable performance over environments.

3. Environmental Stability type three: The eco-valence (*Wi*) was calculated for each genotype using the formula by Wrike,100 s (1962).Regarding the eco-valence (*Wi*), genotype WAB891SG12 was the most stable (*Wi* = 0.1 1)1 followed by NERICA 15 and NERICA 17 (with *Wi* = 0.31 for both) and in spite of their low yields, NERICA.

4. 15 had a higher grain yield in comparison with NERICA 17 (Table 3). In contrast, the 102 genotype NERICA 12 was considered as the least stable (*Wi* = 10.11) in spite of its high mean yield (3.11 t ha$^{-1}$103) which was better than WAB891SG12 (2.8 t ha$^{-1}$104). Evaluation of yield performance of the studied Rice genotypes across locations and seasons reveals that the genotypes NERICA 14, NERICA 4, and WAB891SG12 ranked first using regression indices. The results of the regression analysis do not confirm only one preferred genotype over the other one. From statistical analysis given above it is evident that there is a great temporal and spatial instability in genotypes with respect to yield, and regression analysis cannot capture the overall impact of variability of locations and seasons on yield of genotypes. However, the results of statistical analysis may be considered as an initial screening step in order to arrive to the most preferred alternative. Therefore, multi-criteria analysis that considers effects of yield and yield components need to be adopted as a final scheme to identify the most suitable and stable genotypes in the area of White Nile.

## 3.5 Analysis of Results by Multi-criteria

Following Compromise Programming working procedure, the Lp – distances are minimized to give a compromise solution for each weight set considering yield and yield components. In this study, various criteria (traits) are used to evaluate and rank genotypes of Rice that are shown in table 10.

**Table 10. Relative alternative distance from ideal point (L j) and rank of each genotype 139 for equal and variable criteria weights**

| Status of Weight (wi) Genotypes | Equal weight (wi) | | Agronomist weight (wi) | |
|---|---|---|---|---|
| | Compromise Distance | Rank | Compromise Distance | Rank |
| NERICA 2 | 1.207 | 7 | 0.566 | 9 |
| NERICA 4 | 2.356 | 2 | 0.303 | 2 |
| NERICA 5 | 3.394 | 4 | 0.487 | 6 |
| NERICA 12 | 4.454 | 5 | 0.432 | 5 |
| NERICA 14 | 5.461 | 1 | 0.263 | 1 |
| NERICA 15 | 6.496 | 14 | 0.658 | 13 |
| NERICA 17 | 7.524 | 9 | 0.615 | 10 |
| YUNLU 22 | 8.548 | 16 | 0.734 | 16 |
| YUNLU 24 | 9.603 | 12 | 0.624 | 11 |
| YUNLU 26 | 10.611 | 13 | 0.662 | 14 |
| YUNLU 30 | 11.631 | 6 | 0.394 | 4 |
| YUNLU 33 | 12.644 | 8 | 0.493 | 7 |
| YUNLU 34 | 13.655 | 10 | 0.523 | 8 |
| WAB880-1-38-19-8 | 14.682 | 11 | 0.629 | 12 |
| WAB891SG12 | 15.695 | 15 | 0.686 | 15 |
| WAB-1-38-19-14-P2-HB | 16.744 | 3 | 0.372 | 3 |

For in depth investigations not only yield but also other different criteria were considered. Consequently, two weight groups were employed. In the first group, all criteria have the same weight. In the second, groups, criteria 0weights were assigned in the range of 0.0 to 1.0 by a field agronomist, (Table 5). Table 10 is a compromise solution of the payoff matrix (Table 5a and b) for a condition when the decision maker show's no preferences among the criteria. The condition of no preferences is represented by assigning equal weight to every criterion. Similar tables are constructed for other sets of criterion weights under consideration. Based on multi-criteria analysis given in Table 10, genotype NERICA 14 ranked one in case of both equal and unequal weights. This result is in accordance with the selection made by Finlay and Wilkinson, (1963) index. The genotype NERICA 4 ranked second by compromise programming analysis while it ranked first by Eberhart and Russell, (1966). The Wricke, 128 s (1962) index ranked the genotype WABSG12 and recommend it as first alternative but neither the regression indices or Compromise programming agree with this recommendation. Since multi- objectives analysis considers the impacts of all traits its results can be used as strong selection decision tool. Therefore, the two genotypes, NERICA 14 and YUNLU 33, were classified as high yielding and stable genotypes across environments (locations and years) because of their high performance of grain yield and other traits, with both statistical analysis (regression coefficient close to unity, relatively low mean square deviation from regression, (low eco-valence value) and multi-objective evaluation (top Average ranking).

## 4. CONCLUSIONS

The screened genotypes used in this study exhibited great variability to the measured morphological and agronomic traits of yield, yield components under White Nile State - Sudan conditions. Two genotypes (NERICA 14 and YUNLU 33) yielded approximately more than 3.50 t ha$^{-1}$ 146 with approximately bi-value of 1.00, relatively low mean square deviation from regression, low eco valence value and top average ranking. The yield of these genotypes performed best across environments (locations and seasons) indicating wide adaptability. Also, the study showed that the used stability indices alone cannot reflect the overall impacts of variations in locations or seasons. The adopted approach of combining both regression analyses (as initial screening step) with multicity reanalysis (as confirmation final step) could be used without any loss of efficiency. Hence, the two genotypes could be used in the breeding program and / or may be released to farmers for cultivation in the White Nile State.

## COMPETING INTERESTS

Authors have declared that no competing interests exist

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